ALTERING FLIGHT SCHEDULES

FOR INCREASED FUEL EFFICIENCY

GRADUATE RESEARCH PAPER

June 2015

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Abstract

Air Mobility Command (AMC) has made considerable improvements to reduce fuel consumption over the years, but failed to account for temperature effects in their efficiency equations. The purpose of this research was to analyze the effects of temperature on fuel consumption during different times of the day and months of the year. To accomplish this, the researcher created a temperature model for Charleston Air Force Base (AFB) for all months of the year, and modeled the fuel consumption for a four-hour training flight profile for each hour of the day. After analysis, it is imperative that Charleston AFB alter its training flight schedules to increase fuel efficiency and reduce fuel consumption. Recommendations for policy options include decreasing the amount of day training flights and increasing the amount of night training flights, decreasing the amount of summer training flights (May through August) and increasing the amount of winter training flights (November through February), and applying a similar methodology to ALL flights originating from Charleston AFB. Though C-17 flights at Charleston AFB were the focus of this study, the findings should benefit all C-17 operating locations and other aircraft operated by AMC and the United States Air Force.

To my family. Thank you for all of your love and support.

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I would like to express my sincere appreciation to my faculty advisor, Lieutenant Colonel Adam Reiman, for his guidance and support throughout the course of this thesis effort. His insight and experience was certainly appreciated. I would also like to thank my sponsor, Mr. Donald Anderson from Air Mobility Command, for his support and latitude provided to me in this endeavor.

Joshua W. Ehmen

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ALTERING FLIGHT SCHEDULES FOR INCREASED FUEL EFFICIENCY

I. Introduction

General Issue

The United States Air Force (USAF) is the largest user of aviation fuel in the Department of Defense (DoD), and air mobility operations consume the greatest amount. Rising energy costs consume an increasing percentage of the DoD annual budget, and left unchecked, will decrease the ability to modernize Mobility Air Forces (MAF) weapon systems and to upgrade facilities (HQ AMC, 2014). The Air Force Energy Strategic Plan established the USAF's primary energy goal, a 10 percent efficiency improvement by the year 2020. Fiscal year 2011 was the baseline for measuring progress towards this fuel efficiency goal (Donley and Welsh, 2013).

Air Mobility Command (AMC) uses sortie length (flight time) and cargo weight to predict fuel consumption for the baseline year 2011, and recent years have shown a trend of declining actual fuel consumption when contrasted against the predicted fuel consumption regression from the baseline year. However, actual fuel burn is above the regression's predicted fuel burn average for flights between the months of June and August. We hypothesize that temperature's effect on fuel consumption is missing from the equations, and the potential exists to save a significant amount of money by altering flight patterns to avoid flying during the hottest times of the day.

Problem Statement

To support the Air Force Energy Strategic Plan, AMC established five key factors that affect aircraft fuel consumption: 1) changes in force structure, 2) policies put in place that effect the number of hours flown, 3) the number of user requirements supported by MAF aircraft, 4) process efficiencies, and 5) fuel burn rate efficiency. AMC has made considerable improvements in each area, and has saved over 533 million gallons of fuel and 1.9 billion dollars in fiscal year 2012 and 2013 (HQ AMC, 2014). Though the MAF has made significant progress towards reducing the amount of fuel consumed since fiscal year 2011, they are still in need of further reductions.

AMC uses the following equation to establish a baseline upon which future improvements are measured.

$$\textit{Efficiency} = (\textit{Predicted Burn Rate} - \textit{Actual Burn Rate}) / \textit{Actual Burn Rate} \qquad (1)$$

Predicted Burn Rate comes from a regression equation developed by AMC/A3F, and Actual Burn Rate is reported either by the aircrews via the AMC Fuel Efficiency Office's Air Force Fuel Tracker or aircraft maintainers via GO81 (a maintenance database). Compared to fiscal year 2011, fiscal year 2012 and fiscal year 2013 have shown C-17 fuel burn improvements of 2.3% and 2.8% over the baseline year as seen in Figure 1 below (HQ AMC, 2014). That said, there is an apparent increase in actual fuel burn during the summer months of June through August. Why is fuel efficiency the least during the summer months? Should AMC alter flight schedules to reduce fuel consumption during this period? What, if any, are the consequences of altering the flight schedules?

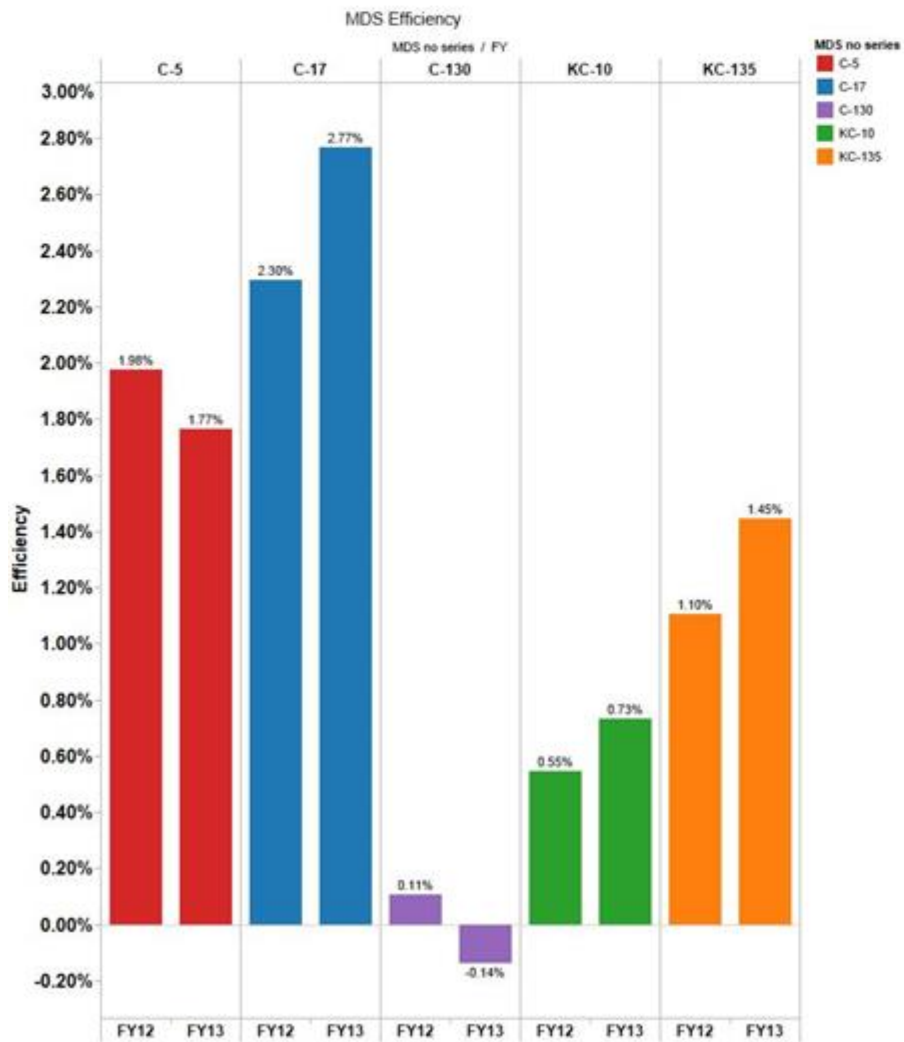


Figure 1. Fuel Burn Rate Efficiency Deltas (HQ AMC, 2014)

The purpose of this study is to analyze the effects of temperature on fuel consumption during different times of the day and months of the year. If significant, the findings of this study should be applied not only to the C-17 community, but also to all other aircraft flown by AMC. By adjusting flight schedules to take advantage of temperature effects, AMC will be one-step closer to the USAF's primary energy goal of a 10 percent improvement by 2020.

Research Questions and Hypotheses

The overall objective of this research is to determine if it is beneficial for AMC to alter flight schedules to reduce fuel consumption. The research questions addressed in this paper include:

1. What are the optimal times during the day to schedule flights to minimize fuel consumption?
2. How are optimal times effected by the month of the year?

The researcher hypothesizes that AMC is not scheduling flights during the optimal times of the day to minimize fuel consumption, and that there is a potential for significant cost savings within AMC and the USAF by making a concerted effort to shift flight times away from the hottest times of the day.

Research Focus

Figure 2 below shows the cost of MAF fuel consumption in fiscal year 2011, fiscal year 2012, and fiscal year 2013. Clearly, the C-17 is responsible for the highest gallons of fuel consumed, and the highest corresponding fuel costs. As a result, this research believes the largest cost savings would be realized by focusing on this aircraft. Using historical fuel, cargo, and flight data from the AMC Fuel Efficiency Office's Air Force Fuel Tracker, and historical temperature data for locations of emphasis, I analyzed whether AMC could save money by altering flight schedules to reduce flying during the hottest times of the day and/or the hottest months of the year. The analysis used Microsoft Excel 2010®. Though C-17 flights were the focus of this study, the findings of this study should benefit all other aircraft flown by AMC.

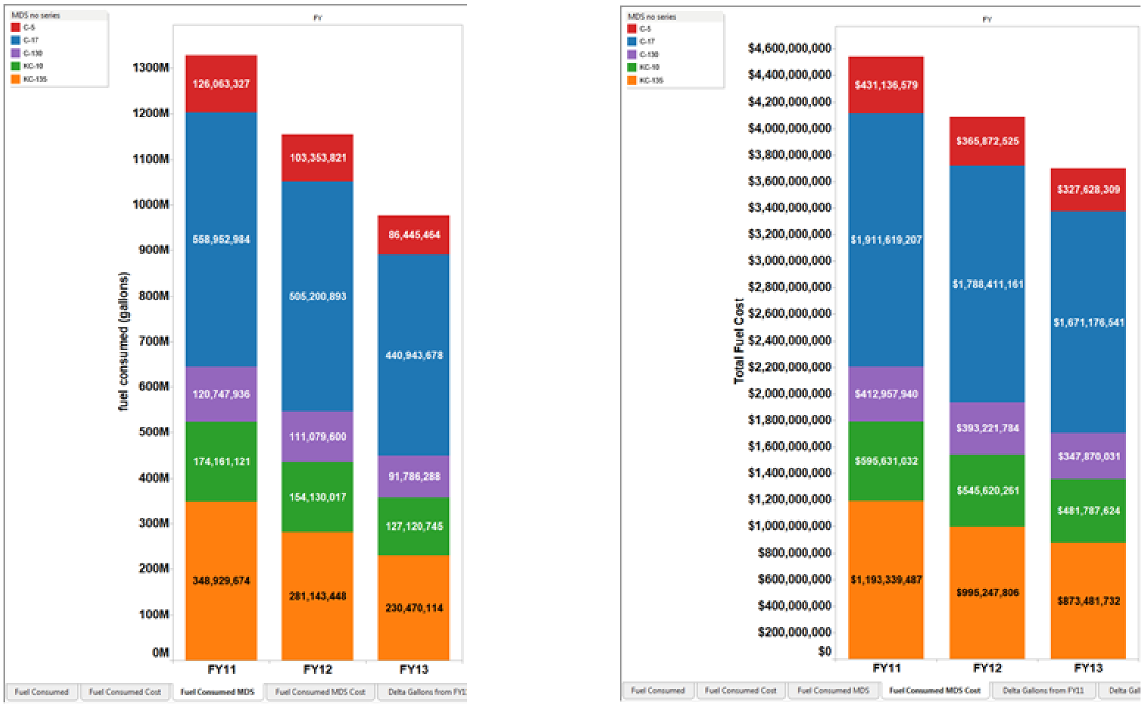


Figure 2. MAF Fuel Cost by Aircraft (HQ AMC, 2014)

II. Literature Review

This literature review examines current DoD, USAF, and Major Command (MAJCOM) energy policies and guidance. It then addresses the regression equations currently used by AMC to assess fuel burn rate changes against a baseline year. Next, it will discuss the effects that temperature has on aircraft performance, with the focus being mainly on the C-17. The weather section also includes methods used by the Air Force Weather Agency to report and model weather, and examines current flying practices at a select C-17 Airlift Wing (AW).

Energy Policies and Guidance

The Secretary of Defense publishes the Quadrennial Defense Review (QDR) every four years, which outlines policy for the DoD. The current QDR, published by Secretary Chuck Hagel, prioritizes three strategic pillars: 1) defending the homeland, 2) building security globally by projecting United States influence and deterring aggression, and 3) remaining prepared to win decisively against any adversary should deterrence fail (Hagel, 2014). In order to remain prepared to win decisively against any adversary, we must continue to innovate, especially during these times of fiscal restraint. Innovation is not only required in the technologies the United States develops, but also in how our forces operate (Hagel, 2014). The DoD currently accounts for 80 percent of the energy consumption within the Federal Government (Donley and Welsh, 2013). Our actions to increase energy and water security will make us a stronger and more effective fighting force. In response to the QDR, the

USAF developed its own comprehensive energy strategy.

USAF Energy Strategic Plan.

The Air Force alone accounts for 48 percent of the total DoD energy consumption, and slightly more than 50 percent of the total DoD energy costs. The vast majority of the Air Force energy consumption and cost is for aviation fuel, which equates to approximately 2.5 billion gallons of fuel annually (Donley and Welsh, 2013). Current and potential concepts of operations require more fuel and energy than previous generations, which carries significant strategic and operational risks and consequences if the Air Force is not prepared.

In response, former Secretary of the Air Force Michael Donley and USAF Chief of Staff General Mark Welsh developed the USAF Energy Strategic Plan to improve on its ability to manage supply and demand in a way that enhances mission capability and readiness. The plan focuses on four priorities: 1) improve resiliency, 2) reduce demand, 3) assure supply, and 4) foster an energy aware culture (see Table 1 below). As part of reducing demand, the USAF is looking to focus on operational and logistical efficiencies as a way to improve its energy security posture while enhancing mission effectiveness, with the goal to improve aviation energy efficiency across all aircraft types by focusing on training and operational effectiveness through innovation and cost-effective investments. The current USAF objective is to improve aviation energy efficiency by 10 percent by the year 2020, using fiscal year 2011 as a baseline, and it hopes to share best practices with its domestic and international partners for efficient fuel usage (Donley and Welsh, 2013).

Table 1. USAF Energy Strategic Plan Priorities (Donley and Welsh, 2013)

AIR FORCE ENERGY STRATEGIC PLAN		
PRIORITY	**INTENT**	**EXPECTED OUTCOME**
Improve Resiliency	↗ Identify vulnerabilities to energy and water supplies, such as physical and cyber attacks or natural disasters ↗ Mitigate impacts from disruptions in energy supplies to critical assets, installations, and priority missions	↗ Improved responsiveness to disruptions to energy and water supplies ↗ Increased ability to quickly resume normal operations and mitigate impact to the mission ↗ Prioritized response plans and solutions to mitigate risk from the tail (logistics supply chain) to the tooth (energy demand in operations)
Reduce Demand	↗ Increase energy efficiency and operational efficiency for Air Force systems and processes without losing mission capabilities	↗ Decreased amount of energy required by Air Force systems and operations ↗ Increased flexibility, range, and endurance in all operations
Assure Supply	↗ Integrate platform-compatible alternative sources of energy ↗ Diversify drop-in sources of energy ↗ Increase access to reliable and uninterrupted energy supplies	↗ Access to backup energy resources and supply chains based on asset and mission priorities ↗ Increased flexibility in all operations ↗ Increased ability to sustain mission
Foster an Energy Aware Culture	↗ Integrate communication efforts using training and education opportunities to increase awareness of energy impacts to mission ↗ Ensure the acquisition process reflects energy as a mission enabler	↗ Increased understanding and awareness of energy and its impacts to the mission ↗ Reduced energy demand through more efficient uses of energy resources ↗ Increased ability to integrate energy considerations in planning activities and other decisions

The Air Force hopes that as energy awareness increases, new ideas and methodologies for operating more efficiently will emerge and push the Air Force towards energy security and sustainability. Pilots, facility energy managers, and operations group commanders make every day decisions to reduce demand for energy (Donley and Welsh, 2013). The Air Force Aviation Operations Energy Plan details the specific energy initiatives the Air Force is implementing for aviation.

Air Force Aviation Operations Energy Plan.

Realizing the need to integrate energy awareness into Air Force operations from

policy guidance contained within Air Force Instructions and Policy Memoranda, to flight procedures implemented at the squadron level, the Air Force released the Aviation Operations Energy Plan (Air Force, 2010). The Aviation Operations Energy Plan aligns with the Strategic Energy Plan. It is comprised of four "pillars": 1) provide leadership in energy management, 2) fly and operate efficiently, 3) instill energy awareness, and 4) maximize the use of technology for fuel efficiency (see Figure 3 below). The Air Force is relying on all of its Airmen to recognize and create opportunities to conserve energy.

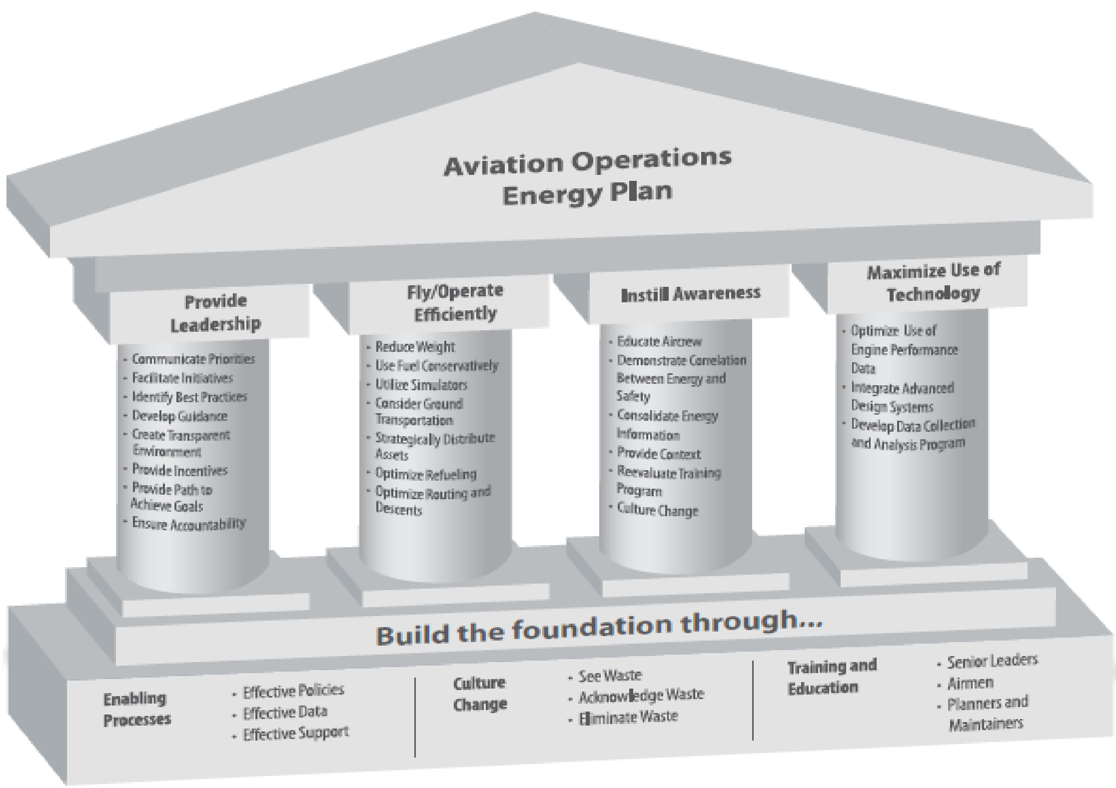


Figure 3. Air Force Aviation Operations Energy Plan Pillars (Air Force, 2010)

Aviation operations involve multiple decision points that influence energy consumption rates. Answering important fuel questions (i.e. desired recovery fuel, flying during a different time of day to consume less fuel, etc.) during the planning phase can result in significant fuel conservation. Another objective is to use simulator capability to the maximum extent possible. The emergence of high fidelity simulators (i.e. the C-17 simulator) enhances training capabilities by allowing training in a range of mission scenarios, and in turn reduces fuel used for training flights and exercises (Air Force, 2010). Additionally, flight simulators assist in extending airframe life cycles and reduce the number of airframes required for training, which frees more aircraft for real-world missions.

It is incumbent upon Air Force leadership to modify standard operating procedures, and encourage a culture of energy conservation for all Airmen to follow. Of the different types of aviation operations, aviation mobility consumes the largest amount of fuel by far (see Figure 4 below). This research will review AMC's plan for reduced fuel consumption.

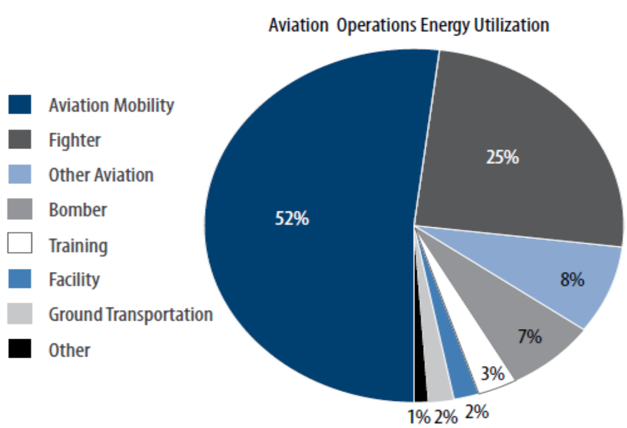


Figure 4. Aviation Operations Energy Utilization (Air Force, 2010)

AMC's 2020 Fuel Consumption Metrics.

Air mobility operations consume the largest amount of aviation fuel in the Air Force, and left unchecked, could decrease the ability to modernize MAF weapons systems and upgrade facilities. In the past, mission *effectiveness* was AMC's primary concern, but now, their concern is for operations to be as *efficient* as effectiveness allows (HQ AMC, 2014). According to AMC, the five key factors that affect aircraft fuel consumption are: 1) changes in force structure, 2) policies put in place that effect the number of hours flown, 3) the number of user requirements supported by MAF aircraft, 4) process efficiencies, and 5) fuel burn rate efficiency (HQ AMC, 2014). Changes in force structure relates to the number of aircraft in the MAF, otherwise known as the Total Aircraft Inventory (TAI). As AMC reduces the fleets of older aircraft (i.e. C-5, KC-135) and increases fleets of newer aircraft (i.e. C-17), they calculate the estimated change in fuel consumption due to these force structure changes (HQ AMC, 2014).

Policy changes refers to decisions made by leadership that either increase or decrease the programmed flight hours. Examples of policy changes that AMC has used include reduced crew ratios, putting aircraft into the Backup Aircraft Inventory (BAI), and reduced copilot seasoning rates (HQ AMC, 2014). AMC is also attempting to extract more fuel efficiency through the increased use of flight simulators for crew training and efficiency, optimized cargo loads, decreased amount of empty legs, and reduced aircraft weight (McAndrews, 2010).

Requirements changes refers to all flight activity flown above the MAF programmed levels. Figure 5 below shows the C-5 has been flying near the

programmed level for all three years depicted, the C-17 and C-130 have reduced flying hours to the programmed level, and the KC-10 and KC-135 were both overflying their programs. A reduction of requirements for the C-5, C-17, or C-130 would not necessarily correspond to a reduction in flying hours or fuel consumption unless there are additional policies or force structure changes, as those aircraft will fly their hours in some other venue to season their pilots. Reducing requirements for the KC-10 or KC-135 would result in reduced flight hours and fuel consumption (HQ AMC, 2014).

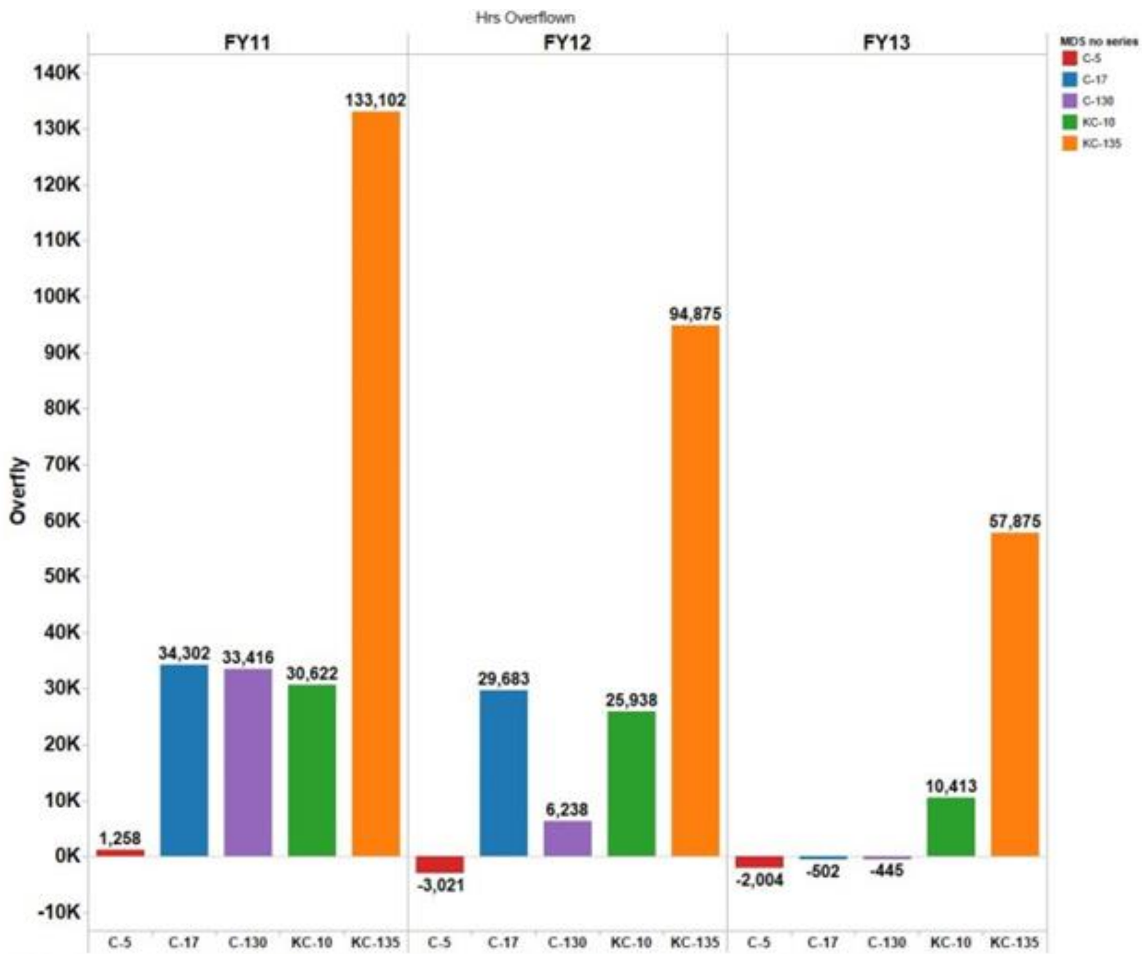


Figure 5. Hours Flown Above Programmed Levels (HQ AMC, 2014)

Process efficiencies save fuel or avoid the consumption of fuel, but do not affect aircraft burn rates. Examples of process efficiencies include utilized ground refueling stops in lieu of air refueling, polar overflights, and optimized diplomatic cleared routings to shorten mission flight times (HQ AMC, 2014). The next section discusses fuel burn rate efficiency, but the fiscal year 2012 and 2013 AMC fuel savings in gallons and dollars can be seen in Tables 2 and 3 below.

Table 2. MAF Fuel Savings in Gallons (HQ AMC, 2014)

	FY12	FY13	Total
Force Structure	- 14,481,558	- 25,250,576	-39,732,134
Policy	- 31,121,969	- 26,857,510	-57,979,479
Requirements	-108,089,950	-285,697,093	-393,787,043
Process Efficiencies	-6,907,884	-6,181,309	-13,089,194
Fuel Burn Rate Efficiency	- 16,364,312	- 12,579,380	-28,943,692
Total	-176,965,673	-356,565,868	-533,531,542

Table 3. MAF Fuel Savings in Dollars (HQ AMC, 2014)

	FY12	FY13	Total
Force Structure	-$ 51,264,714	-$ 95,699,683	-$ 146,964,397
Policy	-$110,171,772	-$ 101,789,964	- $ 211,961,736
Requirements	-$382,638,422	-$1,082,791,979	-$1,465,430,401
Process Efficiencies	-$24,453,910	-$ 23,427,163	-$ 47,881,073
Fuel Burn Rate	-$ 57,929,666	-$ 47,675,849	-$ 105,605,515
Total	-$626,458,484	-$1,351,384,638	-$1,977,843,122

Fuel Burn Rate Efficiency

Figure 6 below shows the relationships between aircraft fuel burn and sortie length and aircraft fuel burn and cargo weight. It is clear that sortie length or cargo weight alone cannot describe fuel burn rates for MAF aircraft. In response, AMC created regression equations for eight Mission Design Series (MDS) aircraft (C-17, C-

5A/C, C-5B, C-5M, C-130H, C-130J, KC-10, and KC-135) to describe the relationship between sortie length and cargo weight for Channel flights, Special Assignment Airlift Mission (SAAM) flights, Contingency flights, Training flights, Exercise flights, and Other flights. To build the regressions, five independent variables were used to predict fuel consumption: 1) sortie length (hours), 2) sortie length squared (hours squared), 3) cargo weight (thousands of pounds), 4) cargo weight squared (thousands of pounds squared), and 5) sortie length multiplied by cargo weight (hours multiplied by thousands of pounds). Figure 7 below plots predicted fuel consumption against actual fuel consumption for C-17 SAAM flights, and the regression outputs for all C-17 categories are located in Appendix A. The R-Squared values for C-17 categories range from 0.954 – 0.987, which shows that the independent variables used to predict C-17 fuel consumption are extremely accurate (HQ AMC, 2014).

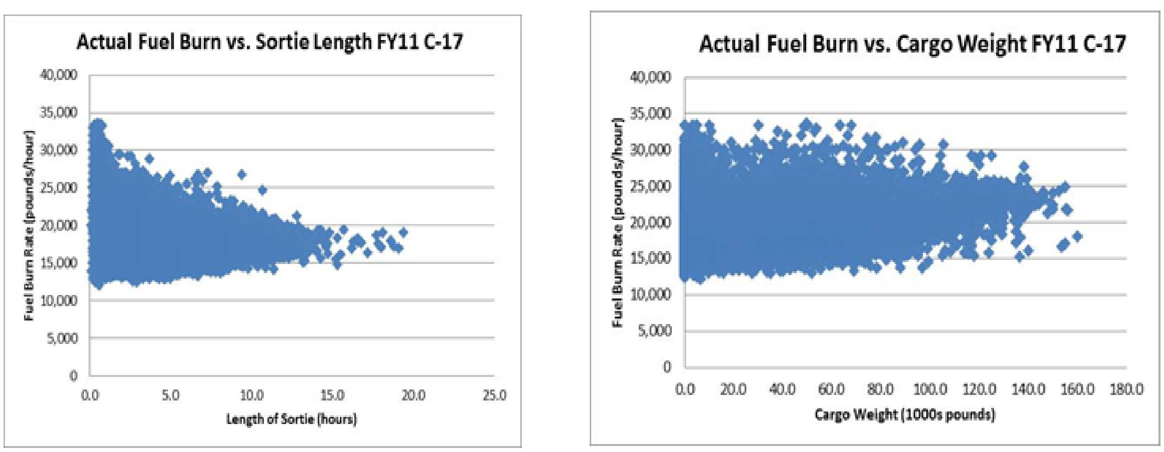


Figure 6. Fuel Burn vs. Sortie Length and Cargo Weight (HQ AMC, 2014)

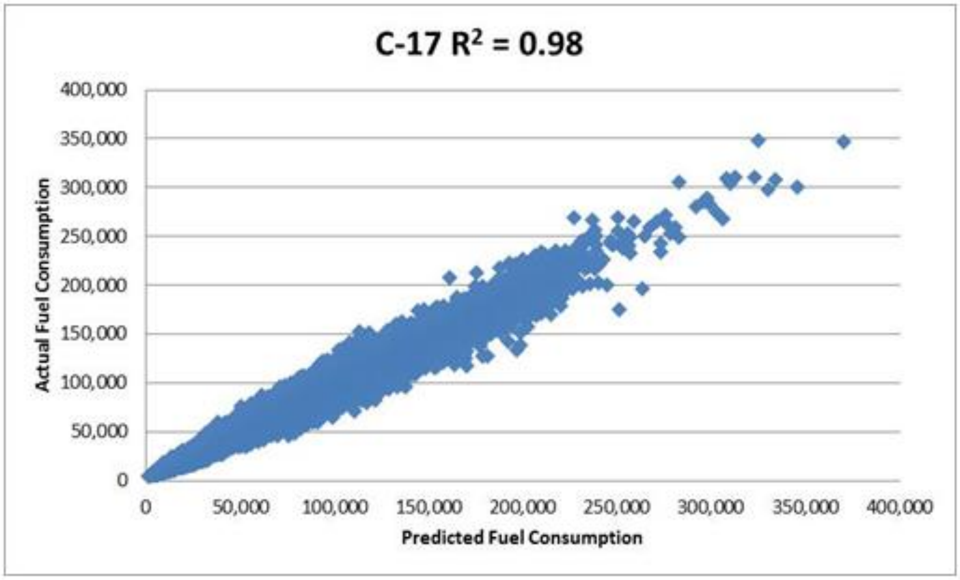


Figure 7. C-17 SAAM Predicted vs. Actual Fuel Consumption (HQ AMC, 2014)

In order to interpret the figures above, AMC expresses the difference between the predicted fuel burn rate and the actual burn rate as a percentage to calculate fuel burn rate efficiency for the baseline year of 2011. Looking at equation 1, predicted burn rates must be higher than actual burn rates to have a positive resulting percentage. However, Figure 8 below shows decreased, and in some cases negative, percentages of fuel burn rate efficiency for C-17 flights between the months of June and August. Why do sortie length and cargo weight fail to accurately predict fuel consumption during these summer months? Temperature has an effect on fuel consumption, and is missing from the regression equations.

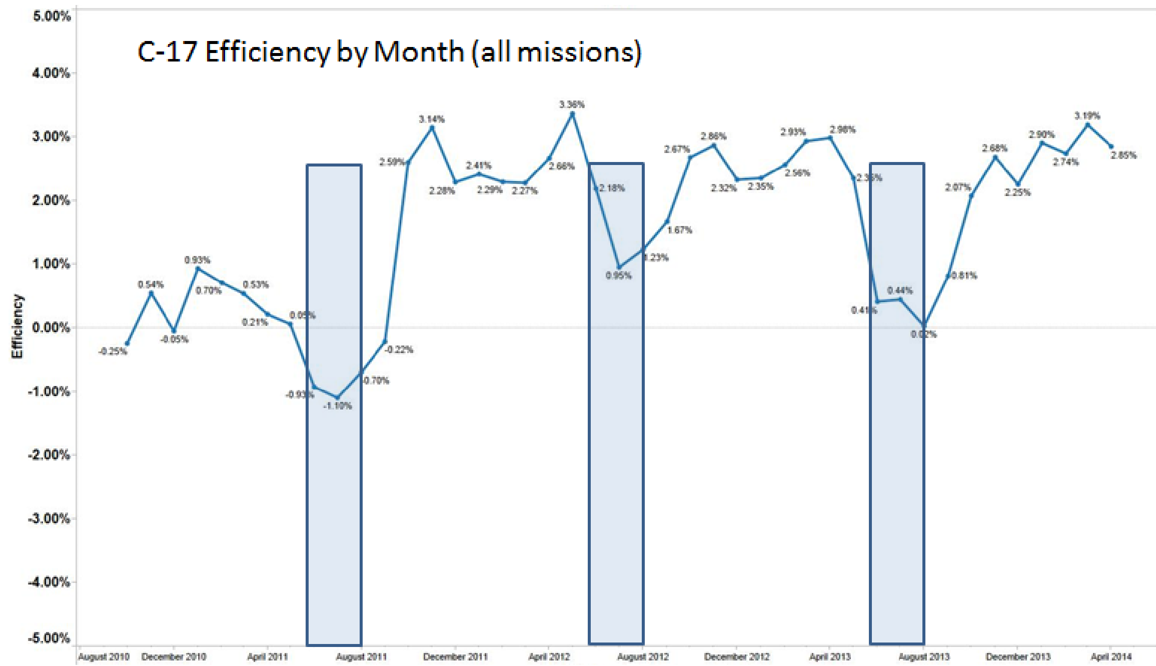


Figure 8. C-17 Burn Rate Efficiency by Month (HQ AMC, 2014)

Effects of Temperature on Fuel Consumption

When referencing an aircraft Technical Order (TO) to determine performance capabilities, the figures and/or charts assume a standard atmosphere, which is 29.92 inches of mercury at 15 degrees Celsius (59 degrees Fahrenheit) at sea level. However, rarely will an aircraft actually operate under conditions that approximate the standard atmosphere. Any increase in temperature or altitude equates to a corresponding decrease in air density, which in turn decreases aircraft performance. As a result, on a hot day, an aircraft will not be able to carry as much payload, and will require a longer runway to takeoff, have a poorer rate of climb, have a faster approach speed, and experience a longer landing roll.

Effects of Temperature on C-17 Performance.

According to Air Force TO 1C-17A-1, temperatures above standard day will decrease rate of climb, and consequently increase time to climb, fuel to climb, and distance to climb. Additionally, at temperatures above 30 degrees Celsius (87 degrees Fahrenheit), C-17 maximum thrust decreases with increasing ambient temperature and altitude; intermediate and maximum continuous thrust settings are also flat rated, and climb gradient decreases above this temperature (see Figure 9 below).

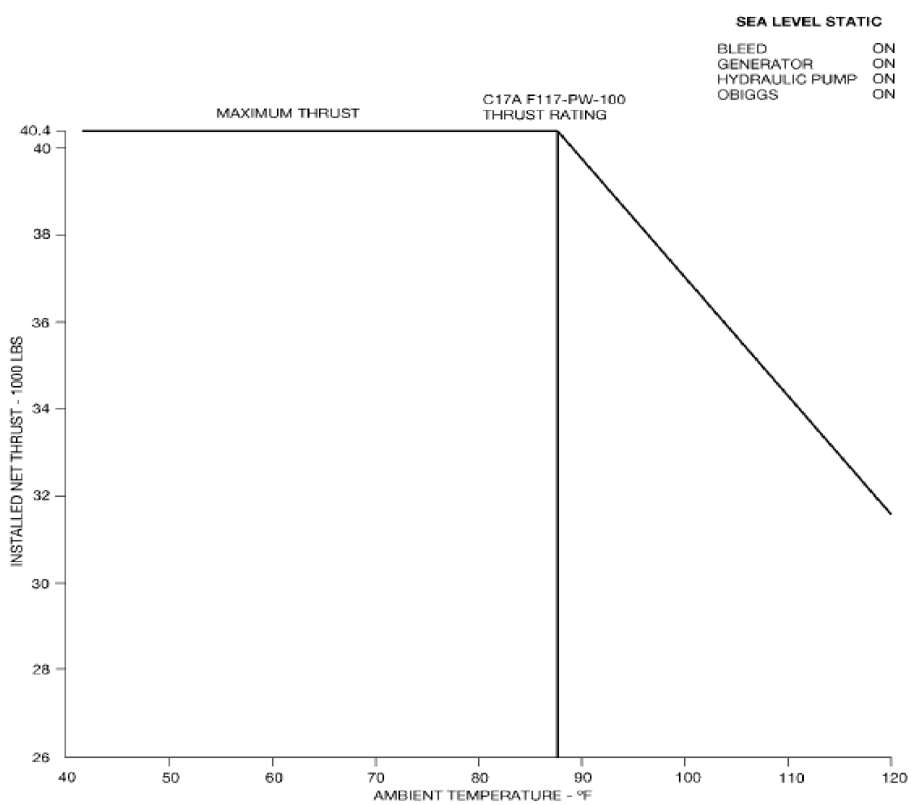


Figure 9. Flat Rated Engine (Air Force, 2013)

Air Force TO 1C-17A-1-1, the C-17 performance manual, reiterates the effect temperature has on C-17 climb performance, and each chart provided in Part 4 (Enroute

Climb) has correction grids to account for other than standard day temperatures. See Figure 10 below for the expected differences in time, distance, and fuel to climb when other than standard day. For example, a 20,000-pound fuel to climb at standard day could increase to 27,500 pounds at 30 degrees Celsius (87 degrees Fahrenheit), or 39,000 pounds at 35 degrees Celsius (95 degrees Fahrenheit).

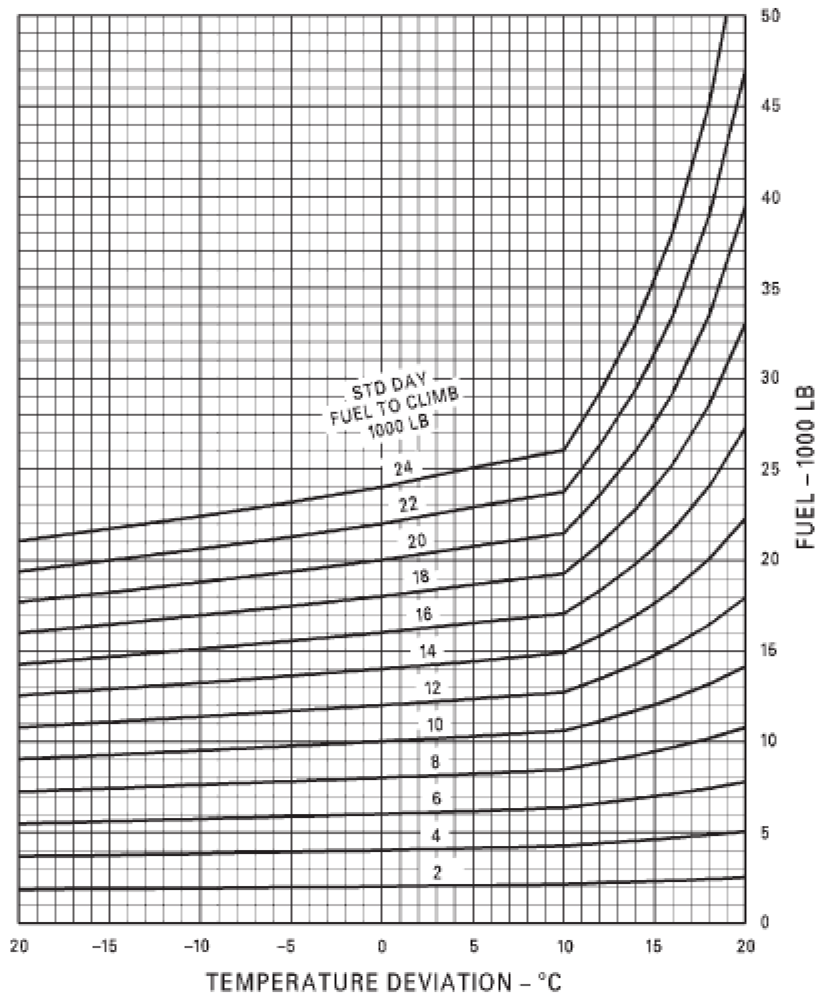


Figure 10. Effect of Temperature on Fuel Burned During Climb (Air Force, 2013)

Also worth noting from Air Force TO 1C-17A-1-1 is that temperatures above standard day plus 10 degrees Celsius (77 degrees Fahrenheit) result in a degradation in cruise and service ceiling capability, which results in an increased fuel burn for flying at lower altitudes. For every 10 degrees Celsius increase from standard day, the specific range and integrated range capabilities reduce by 1 percent, the fuel flow increases by 3 percent, and the integrated time capability decreases by 3 percent. Finally, the decrease in available thrust from increased temperatures results in an increased flap index used for final approach and landing.

As stated earlier, the ability to answer important fuel questions (i.e. whether to fly during a different time of day to consume less fuel) during the mission planning phase can result in significant fuel conservation. The Air Force has multiple weather reporting and modeling applications available for aircrews to plan around the higher temperatures, and the next section will discuss a few of them.

Air Force Weather Reporting and Modeling.

In the 1990s, the Air Force Weather Agency (AFWA) developed a reengineering plan to provide more accurate, timely, and relevant weather support to the warfighter. The result was an alignment into 2 strategic centers (AFWA and Air Force Combat Climatology Center), 8 Operational Weather Squadrons (OWS), and 219 Combat Weather Teams (CWT). Currently, most OWS are aligned with Numbered Air Force (NAF) headquarters or MAJCOMs, but they are designed to shift seamlessly underneath the Warfighting Headquarters (WFHQ) if required (AFWA, 2005). AFWA provides multiple benefits to the MAF, and Computer Flight Plans (CFP) and temperature modeling are a few of them.

The ability to use meteorological information, such as wind and temperature, allows CFP systems to improve the accuracy of flight plans and air navigation, and improve safety of flight. Additionally, fuel optimized CFPs result in a savings in fuel costs. Today, the military services operate two flight-planning systems. AMC runs the Advanced Computer Flight Plan (ACFP) system for the Air Force, and the Navy's Fleet Numerical Meteorology and Oceanography Center runs the Optimum Path Aircraft Routing System (OPARS) (AFWA, 2005).

The ACFP contains aircraft-specific information, such as engine performance data, which use weather information as one input. To ensure the most accurate weather information, wind and temperature fields from the Navy Operational Global Atmospheric Prediction System (NOGAPS) model running at AFWA are sent to AMC for use in CFP production. The ACFP has shown an improvement over previous CFP systems of 2.8 percent in fuel savings and a 2.3 percent reduction in flight time, and the potential exists to reduce fuel consumption by an additional 1 to 2 percent when integrated with the Worldwide Aeronautical Route Planner (WARP) to provide three-dimensional optimum route selection (AFWA, 2005).

There are three methods to submit flight plan requests to the ACFP systems. The first method is the Web-based interface, which accesses ACFP via a Secure Socket Layer (SSL) connection to the ACFP server. The second method is the client-server interface, which allows users to work offline and then submit flight plan requests via the Web-based server. The third method is the Web services capability, which allows external systems, such as Portable Flight Planning Software (PFPS), to request wind and

temperature data from ACFP (HQ AMC, 2005). All three methods are capable of receiving AFWA wind and temperature data.

NOGAPS wind and temperature data passes through AFWA, and is provided in a 1-degree grid format, updated every 12 hours to provide the most accurate and current upper air weather data, and covers 96 hours into the future. This is the ideal model to use when planning using ACFP. For weather input beyond 96 hours, ACFP uses AFWA climatological (CLIMO) weather data in its calculations. CLIMO provides weather based on monthly averages, is updated approximately every five years, and the weather for every day in any given month is the same (HQ AMC, 2005). When combining accurate weather data with ACFP's ability to compute flight plans for optimum fuel, one can see how such fuel savings have been realized. Another service provided by AFWA, temperature modeling, can aid aircrews in determining the optimal times of the day to fly.

Airfields at deployed locations in the Middle East typically see temperatures in excess of 48 degrees Celsius (120 degrees Fahrenheit), or 33 degrees Celsius above standard day. Changes in density altitude during the hot days were restricting the performance of KC-135 aircraft operating out of an airfield in Qatar, resulting in less available power, thrust, and lift. Because of these losses, the tankers were carrying lower fuel loads than calculated during mission planning so they could safely takeoff, which affected fuel offloads to fighter aircraft and total flight time availability to provide air-refueling support. In response, the Air Force Combat Climatology Center provided summarized temperature and pressure data for that airfield to the mission planners, which allowed them to improve their aircraft gross weight calculations to better support the fight (AFWA, 2005).

There are multiple acceptable methods to model temperature. Figure 11 below illustrates the impact that Latitude has on average monthly temperature at sea level, using temperature data compiled by the University of Delaware between 1981 and 2010. Note that temperatures hardly vary from month to month nearest the equator, vary slightly with increased Latitude South of the Equator, and vary greater with increased Latitude North of the Equator. Regression equations were created, using this temperature data, to determine the average temperature for Latitude for each month (Reiman, 2014).

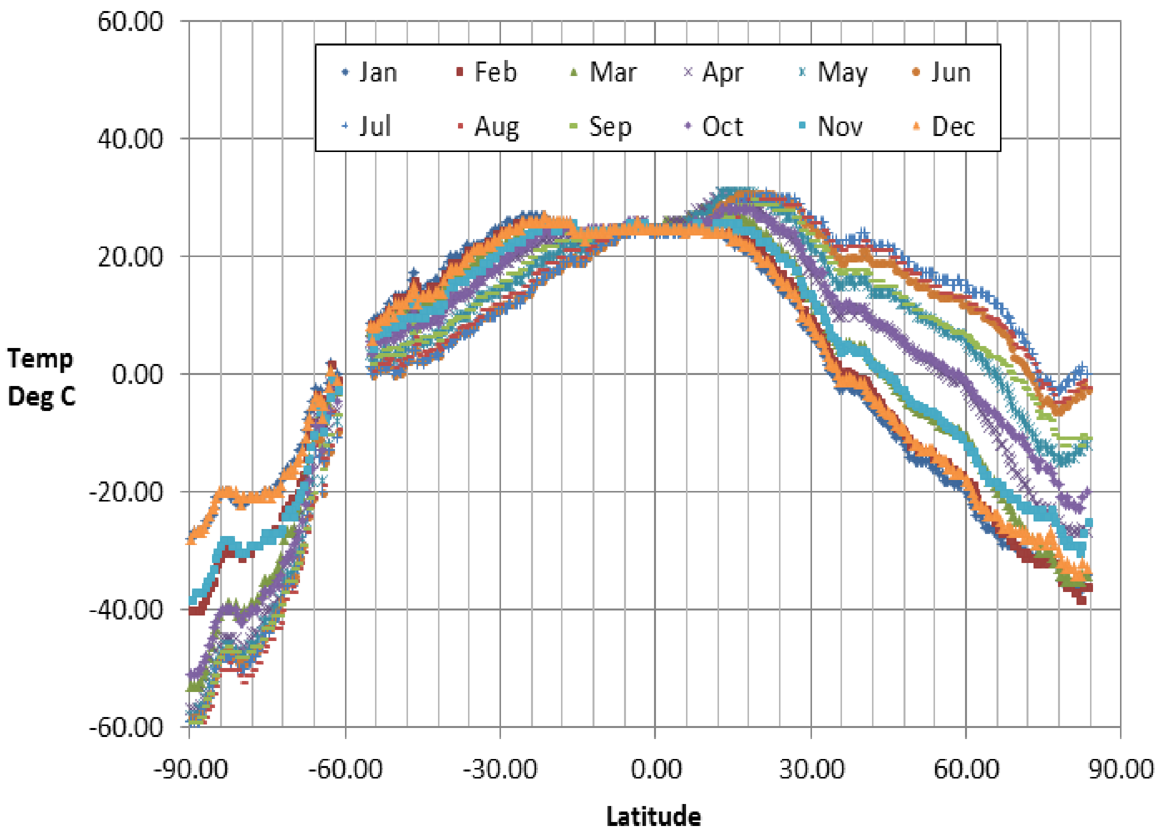


Figure 11. Average Monthly Sea Level Temperature vs. Latitude (Reiman, 2014)

Another method to model temperature is to display hourly temperature, by month, for a particular airfield. Figure 12 below illustrates hourly temperatures for Charleston AFB, one of the larger C-17 bases, during November of 2010. Note the coolest hourly temperatures observed are between 0100 and 0700 local time, and is approximately 36 degrees Fahrenheit (2 degrees Celsius). The highest hourly temperature observed is at 1600 local time, and is approximately 69 degrees Fahrenheit (20 degrees Celsius).

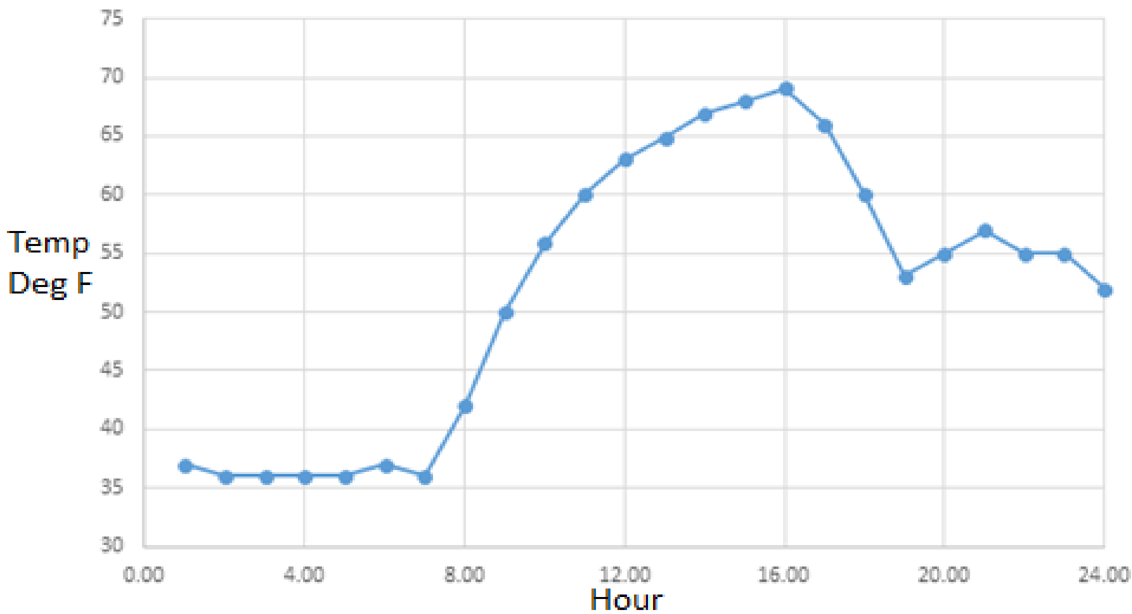


Figure 12. Charleston AFB Hourly Temperature, November 2010

Referencing the literature above, an objective of the USAF Energy Strategic Plan was to share best practices with domestic and international partners for efficient fuel usage. One practice that Continental Airlines has adopted is to schedule certain flights to takeoff later at night, to reduce fuel costs associated with the cooler temperatures (Lesinski, 2011). Figure 13 below shows the midpoint time of C-17 Training flights

operating out of Charleston AFB during November of 2010. Significant fuel savings could be achieved if Charleston were to shift the midpoint time earlier or later to avoid flying during the hottest time of the day, and the savings could be even greater during the hotter summer months.

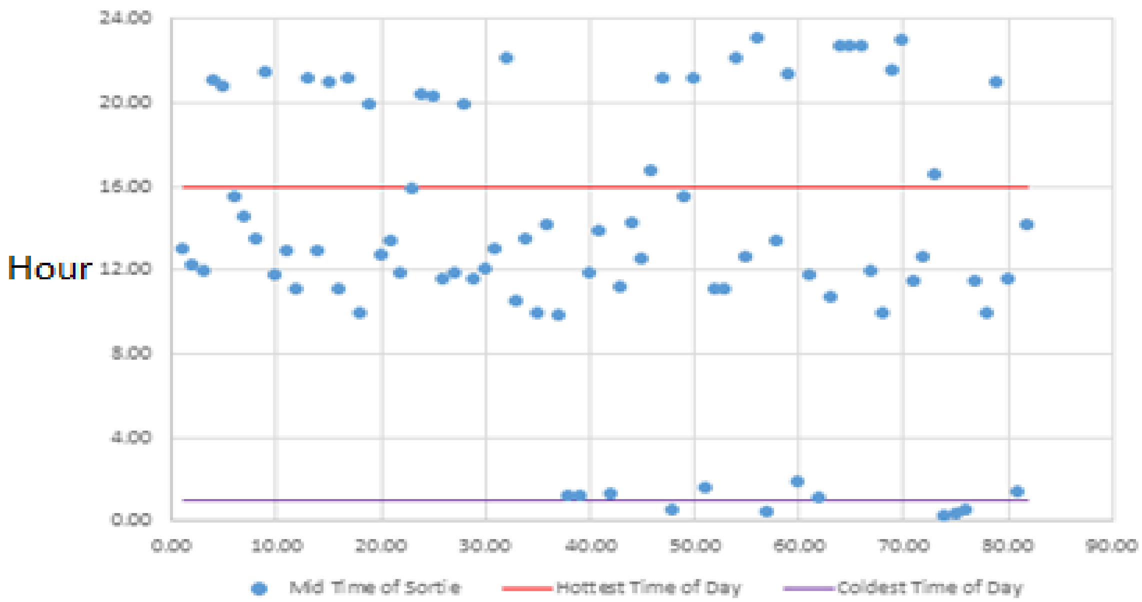


Figure 13. Midpoint Times of C-17 Training Flights, November 2010

Multiple other gains are possible by flying during cooler times of the day. Examples of these gains include reduced Critical Field Length (CFL) required for takeoff, the ability to carry more payload, higher rate of climb, slower approach speed, shorter landing roll, and increased aircraft performance in general for desired maneuvers (i.e. threat reactions and maneuvering). The next section will detail the methodology used to determine whether AMC should alter flight schedules to avoid flying during the hottest times of the day.

III. Methodology

Methodology of the Model

A historical review of the AMC Fuel Efficiency Office's Air Force Fuel Tracker yielded 153,501 C-17 flights that occurred between October 2010 and April 2014. After filtering the flights by departure location, the home station C-17 AFB with the highest number of records was Charleston AFB with 8,665. A great deal of information was needed from a variety of sources to: 1) develop an effective temperature model for Charleston AFB for all months of the year, 2) model the fuel consumption for a four-hour flight profile for each hour of the day, and 3) show the differences in fuel consumption when compared against a baseline time of day. The methodology begins with the development of a temperature model for Charleston AFB.

Charleston AFB Temperature Model

The intent of the Charleston AFB temperature model is to estimate the hourly weather for each month of the year. The model obtained historic weather information from the Weather Underground database (http://www.wunderground.com). This website contains an almanac of complete historic hourly, daily, weekly, and monthly weather information by location, and has temperature, atmospheric pressure, wind direction and speed, precipitation, and sky condition for the time in question. From the Weather Underground homepage, enter "Charleston Air Force Base-International" in the search panel at the top, and click the "View Calendar Forecast" hyperlink

halfway down the Charleston page. From this page, the researcher collected four years' worth of daily data beginning on January 1st, 2011.

Each "Weather History Date" contained a complete hourly weather history for Charleston AFB on the dates of interest. To make sense of this data, the researcher clicked the "Comma Delimited File" hyperlink at the bottom of the page, copied all daily data, and pasted the data into Microsoft Excel 2010®. He then created a tab for each calendar month, and delimited all monthly data using the "Text to Columns" function from the "Data" tab once consolidated. In total, this methodology collected 39,445 rows of data for each day between January 1st, 2011, and December 31st, 2014.

For each calendar month, the researcher created additional columns to convert temperature from degrees Fahrenheit to degrees Celsius, and the time of each observation from Eastern Standard Time to hour to the hundredth decimal place. Using Equation 2 below, he created 12 regression equations (one for each month) to predict degrees Celsius at Charleston AFB for every hour of the day. Figure 14 displays a sample of the regression methodology for the month of July (the remaining regression equations are located in Appendix B).

$$\acute{\alpha} = \beta_0 + \beta_1 t + \beta_2 \sin\left(\frac{2\pi t}{L}\right) + \beta_3 \cos\left(\frac{2\pi t}{L}\right) + \beta_4 \sin\left(\frac{4\pi t}{L}\right) + \beta_5 \cos\left(\frac{4\pi t}{L}\right)$$

where $\acute{\alpha}$ = degrees Celsius, t = time in hours, and L = 24 hours (2)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.71931305
R Square	0.517411264
Adjusted R Square	0.516684911
Standard Error	2.2147604
Observations	3328

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	17470.76113	3494.152226	712.3416241	0
Residual	3322	16294.95358	4.90516363		
Total	3327	33765.71471			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
β_0	27.66952391	0.151458458	182.6872157	0	27.37256259	27.96648523	27.37256259	27.96648523
β_1	-0.017962625	0.01181219	-1.5206854	0.128433974	-0.04112253	0.00519728	-0.04112253	0.00519728
β_2	-2.346743836	0.10450895	-22.45495569	4.3994E-104	-2.551652271	-2.141835401	-2.551652271	-2.141835401
β_3	-2.199213465	0.05563396	-39.53005458	1.9253E-280	-2.308293765	-2.090133164	-2.308293765	-2.090133164
β_4	0.409237877	0.06980763	5.862365995	5.00973E-09	0.272367568	0.546108186	0.272367568	0.546108186
β_5	0.596119892	0.055136544	10.81170211	8.41956E-27	0.488014863	0.70422492	0.488014863	0.70422492

Figure 14. July Charleston AFB Temperature Regression Model

The degrees Celsius equation for July contains an R-Squared value of 0.52, with a minimum regression value of 24.43 degrees Celsius at approximately 5:00 AM and a maximum regression value of 31.15 degrees Celsius at approximately 2:00 PM. The difference between the minimum and maximum value is 6.72 degrees Celsius, which results in an average increase or decrease of 0.56 degrees Celsius per hour throughout the day. Figure 15 displays the results of the July regression equation, compared to the 3,328 data points between 2011 and 2014. Note that the regression equation appears to follow the average value of the data points for each hour, which makes sense considering data for all days in July (cooler average temperatures in the beginning of the month versus warmer average temperatures at the end) are included.

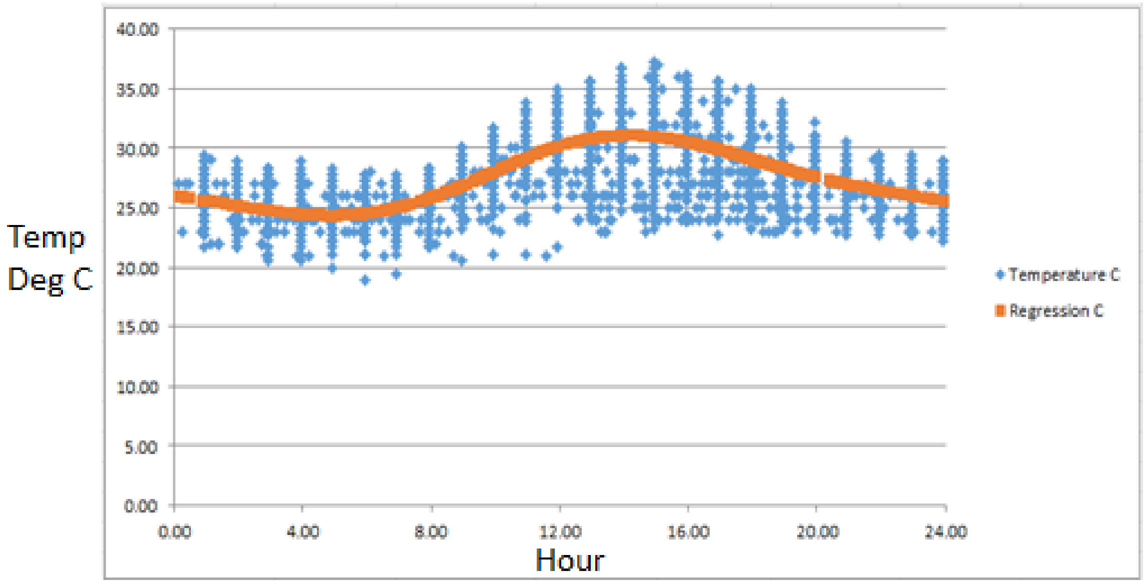


Figure 15. July Charleston AFB Temperature Scatterplot

Table 4 below provides a summary of the results from the regression equations for each hour of the day at Charleston AFB throughout the year. On average, 5:00 AM yields the coolest temperature of the day and 2:00 PM yields the warmest temperature of the day. January at 6:00 AM registers the coolest temperature of the year (6.14 degrees Celsius), and July at 2:00 PM registers the warmest temperature of the year (31.15 degrees Celsius). Following the modeling of temperature, the methodology will next model the fuel consumption for a four-hour flight profile at Charleston AFB.

Table 4. Summary of the 12 Charleston AFB Temperature Regression Equations

	January	February	March	April	May	June	July	August	September	October	November	December
12:00 AM	8.04	9.70	12.15	17.52	21.49	24.60	26.07	25.43	22.84	17.54	11.60	10.98
1:00 AM	7.88	9.47	11.78	17.03	20.78	24.08	25.64	25.02	22.55	17.24	11.19	10.70
2:00 AM	7.58	9.18	11.40	16.53	20.12	23.56	25.21	24.59	22.20	16.88	10.69	10.30
3:00 AM	7.14	8.85	11.02	16.02	19.56	23.09	24.81	24.19	21.80	16.45	10.15	9.83
4:00 AM	6.64	8.53	10.66	15.60	19.19	22.76	24.52	23.87	21.42	16.00	9.70	9.38
5:00 AM	6.25	**8.35**	**10.44**	**15.35**	**19.12**	**22.66**	**24.43**	**23.72**	**21.19**	15.66	**9.47**	**9.13**
6:00 AM	**6.14**	8.44	10.48	15.41	19.40	22.88	24.62	23.84	21.21	**15.59**	9.62	9.22
7:00 AM	6.46	8.91	10.87	15.87	20.08	23.46	25.13	24.27	21.58	15.92	10.24	9.76
8:00 AM	7.28	9.79	11.67	16.77	21.13	24.39	25.94	25.04	22.34	16.73	11.34	10.76
9:00 AM	8.56	11.06	12.87	18.07	22.44	25.59	26.99	26.09	23.44	17.99	12.81	12.14
10:00 AM	10.15	12.56	14.34	19.65	23.87	26.92	28.16	27.30	24.77	19.59	14.49	13.72
11:00 AM	11.82	14.11	15.93	21.30	25.26	28.22	29.30	28.53	26.14	21.33	16.12	15.27
12:00 PM	13.31	15.47	17.41	22.81	26.42	29.31	30.25	29.60	27.36	22.94	17.46	16.54
1:00 PM	14.37	16.45	18.58	23.97	27.24	30.05	30.89	30.38	28.25	24.20	18.33	17.34
2:00 PM	**14.84**	**16.90**	19.27	24.63	**27.64**	**30.37**	**31.15**	**30.77**	**28.68**	24.91	**18.61**	**17.56**
3:00 PM	14.68	16.77	**19.40**	**24.73**	27.59	30.26	31.02	30.74	28.61	**24.99**	18.29	17.19
4:00 PM	13.96	16.14	19.00	24.29	27.17	29.78	30.57	30.33	28.10	24.46	17.50	16.35
5:00 PM	12.85	15.13	18.15	23.44	26.47	29.04	29.89	29.64	27.25	23.46	16.39	15.21
6:00 PM	11.58	13.93	17.02	22.32	25.61	28.17	29.10	28.80	26.25	22.18	15.18	14.00
7:00 PM	10.38	12.74	15.80	21.13	24.69	27.28	28.30	27.92	25.24	20.85	14.04	12.89
8:00 PM	9.41	11.72	14.64	20.00	23.79	26.46	27.59	27.11	24.36	19.65	13.12	12.02
9:00 PM	8.76	10.94	13.67	19.05	22.95	25.76	26.99	26.43	23.68	18.70	12.44	11.44
10:00 PM	8.42	10.42	12.92	18.28	22.18	25.15	26.49	25.87	23.20	18.03	11.97	11.10
11:00 PM	8.27	10.09	12.37	17.67	21.44	24.62	26.05	25.41	22.87	17.59	11.62	10.89

Charleston AFB Fuel Consumption Model

After completion of the temperature model for Charleston AFB, the researcher developed a model to estimate the fuel consumption for a four-hour C-17 flight profile at different temperatures. The methodology selected the four-hour flight duration because the scheduled time for the average C-17 training flight at Charleston AFB between October 2010 and April 2014 was 4.17 hours, with an actual time of 3.71 hours. The researcher planned the flight using Combat Flight Planning Software (CFPS), the primary route-planning interface for C-17 crews; CFPS uses aircraft performance data from TO 1C-17A-1-1 for accurate estimates. As part of the pre-mission configuration, the researcher selected C-17A, 80,000 pounds of fuel at engine

start, zero pounds of cargo, 2,500 pounds of fuel for engine start, taxi and takeoff, and 500 pounds of fuel for the approach and landing.

The researcher created the flight profile with reference to the Charleston AFB In-Flight Guide, which provides information and guidelines for aircrew operations in the local flying training area. The profile consisted of a departure to 11,000 feet, descent to a tactical low-level route, climb to 26,000 feet for air refueling with a KC-135, then descent for an approach to Charleston AFB (see Appendix C). Additionally, the researcher planned the flight using calm winds, and decreased temperature by two degrees Celsius per 1,000 feet of altitude at waypoints throughout the flight.

After the creation of the flight profile, the researcher input a temperature of -4 degrees Celsius (20 degrees below standard day, the lower limit for CFPS) for Charleston AFB at the takeoff and landing waypoints, and decreased the temperature accordingly at other waypoints throughout the route. The researcher did this 39 more times until reaching 35 degrees Celsius (20 degrees above standard day, the upper limit for CFPS), and recorded the fuel consumed for each iteration. Temperature and fuel consumed were input into Microsoft Excel 2010®. Figure 16 and 17 below contain the resulting scatterplot and regression.

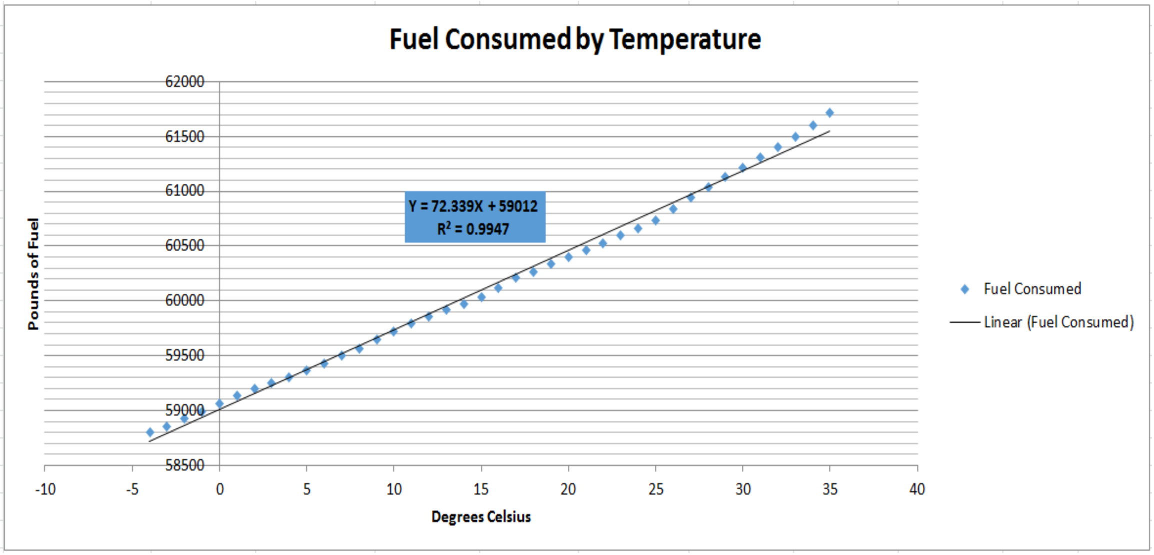


Figure 16. Fuel Consumed by Temperature

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.997352444
R Square	0.994711897
Adjusted R Square	0.994572737
Standard Error	62.46645514
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	27891685.3	27891685.3	7147.942231	7.12825E-45
Residual	38	148278.2047	3902.058018		
Total	39	28039963.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
β_0	59012.49221	16.53592751	3568.744008	1.3473E-106	58979.01698	59045.96745	58979.01698	59045.96745
β_1	72.33921201	0.855624589	84.54550391	7.12825E-45	70.60709058	74.07133343	70.60709058	74.07133343

Figure 17. Fuel Consumed by Temperature Regression Model

Based on the coefficient values above, the equation for fuel consumed during the four-hour flight profile at Charleston AFB is:

$$\omega = \beta_0 + \beta_1 \acute{\alpha},$$

where ω = fuel consumed in pounds (3)

The fuel consumed equation contains an R-Squared value of 0.9947, which suggests temperature can predict fuel consumed with extreme accuracy. The fuel consumed over the 4-hour flight changes by approximately 72 pounds of fuel (10.7 gallons) for every degree Celsius, with a minimum regression value of 58,723 pounds of fuel at -4 degrees Celsius and a maximum regression value of 61,544 pounds of fuel at 35 degrees Celsius. The difference between the minimum and maximum value is 2,821 pounds of fuel (421 gallons).

Table 5. Fuel Consumed During the Four-Hour Flight throughout the Year

	January	February	March	April	May	June	July	August	September	October	November	December
12:00 AM	59594	59714	59891	60280	60567	60792	60898	60852	60665	60281	59852	59807
1:00 AM	59583	59698	59865	60244	60516	60755	60867	60822	60644	60260	59822	59787
2:00 AM	59561	59677	59837	60208	60468	60717	60836	60792	60618	60234	59786	59758
3:00 AM	59529	59652	59809	60172	60427	60683	60807	60762	60589	60202	59747	59723
4:00 AM	59493	59629	59784	60141	60401	60659	60786	60739	60562	60170	59714	59691
5:00 AM	59464	**59616**	**59768**	**60123**	**60395**	**60651**	**60780**	**60729**	**60545**	60146	**59698**	**59673**
6:00 AM	**59457**	59623	59770	60127	60416	60667	60793	60737	60547	**60140**	59708	59680
7:00 AM	59480	59657	59799	60161	60465	60709	60830	60768	60573	60164	59753	59718
8:00 AM	59539	59721	59857	60226	60541	60777	60889	60824	60628	60223	59833	59791
9:00 AM	59632	59812	59943	60320	60636	60864	60965	60900	60708	60314	59939	59891
10:00 AM	59747	59921	60050	60434	60739	60960	61050	60988	60804	60430	60060	60005
11:00 AM	59868	60033	60165	60553	60839	61054	61132	61076	60904	60555	60178	60117
12:00 PM	59975	60132	60272	60662	60924	61132	61201	61154	60992	60672	60276	60209
1:00 PM	60052	60202	60356	60746	60983	61186	61247	61210	61056	60763	60338	60267
2:00 PM	**60086**	**60235**	60406	60794	**61012**	**61209**	**61266**	**61238**	**61087**	60814	**60358**	**60283**
3:00 PM	60074	60226	**60416**	**60801**	61009	61202	61257	61236	61082	**60820**	60336	60256
4:00 PM	60022	60180	60387	60770	60978	61167	61224	61207	61045	60782	60278	60195
5:00 PM	59942	60107	60325	60708	60928	61113	61175	61157	60984	60710	60198	60113
6:00 PM	59850	60020	60244	60627	60865	61050	61117	61096	60911	60617	60110	60025
7:00 PM	59763	59934	60155	60541	60798	60986	61060	61032	60838	60521	60028	59945
8:00 PM	59693	59860	60072	60460	60734	60927	61008	60974	60775	60434	59961	59882
9:00 PM	59646	59804	60001	60390	60673	60876	60965	60924	60726	60365	59912	59840
10:00 PM	59621	59766	59947	60335	60617	60832	60929	60884	60691	60317	59878	59815
11:00 PM	59611	59743	59907	60291	60564	60793	60897	60851	60667	60285	59853	59800

Table 5 above combines the information found in Table 4 with Equation 7, to provide an estimation of fuel consumed during the four-hour flight for each hour of the

day at Charleston AFB throughout the year. As in Table 4, on average, 5:00 AM yields the lowest fuel consumption of the day and 2:00 PM yields the highest fuel consumption of the day. January at 6:00 AM registers the lowest fuel consumption of the year (59,457 pounds of fuel), and July at 2:00 PM registers the highest fuel consumption of the year (61,266 pounds of fuel). The methodology used to show the differences in fuel consumption when compared against a baseline time of day will be detailed next.

Comparing Fuel Consumption against Baseline Time of Day

After development of the temperature and fuel consumption models for Charleston AFB, the primary goal of this research was to identify a baseline time of day and make comparisons of fuel consumption by shifting the baseline time earlier or later in the day. The researcher used the AMC Fuel Efficiency Office's Air Force Fuel Tracker to establish the baseline time of day, but first needed to narrow the 153,501 C-17 flights to a representative sample. The researcher was able to narrow the list to 24,581 by filtering only "Training" MDS type and mission class flights, and to 6,516 after filtering "437 AW" as the aircraft wing and "315 AW and 437 AW" as the aircrew wing. Filtering out "OGS" (Special Operations Low Level) flights brought the list to 6,370. These types of flights are Joint Chiefs of Staff directed, and there is not much flexibility to alter their times. Filtering only entries that departed and arrived at Charleston AFB yielded 4,074 entries, and 3,264 remained after removing airdrop flights. Finally, after filtering flights that did not tanker any fuel, had less than 5,000 pounds of cargo, and did not divert, the final list was narrowed to 3,007 C-17 airland training flights.

The methodology added columns for the narrowed list of C-17 airland training

flights to convert the departure and arrival times from Greenwich Mean Time to Eastern Standard Time, and to calculate the midpoint time of each flight by averaging the departure and arrival times. Additionally, the researcher created columns to identify each month's hottest and coldest hour of the day to display on each month's scatterplot. Figure 18 depicts July's midpoint times for each flight, and the remaining months are located in Appendix D.

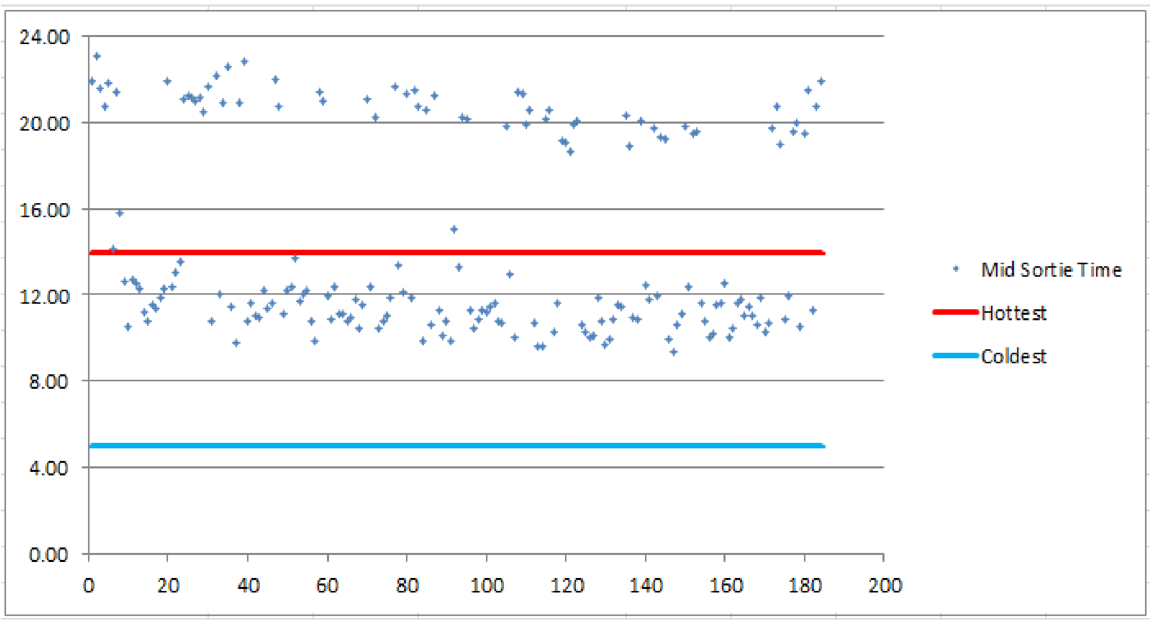


Figure 18. July Charleston AFB Midpoint Flight Time Scatterplot

Note that the morning flights in July appear centered around 11:00 AM and the evening flights appear centered around 8:00 PM. An analysis of the descriptive statistics in Table 6 below confirm the mean midpoint flight time for the 184 flights in July as 14.55 hours (2:33 PM), and the mean midpoint flight time for the 121 flights between 7:00 AM and 4:00 PM in July as 11.34 hours (11:20 AM). These times will

serve as the baseline times of day for July.

Table 6. July Charleston AFB Midpoint Flight Time Descriptive Statistics

Mid Sortie Time			*0700-1600 Mid Sortie Time*	
Mean	14.55		Mean	11.34
Standard Error	0.34		Standard Error	0.10
Median	11.95		Median	11.21
Mode	10.49		Mode	10.49
Standard Deviation	4.58		Standard Deviation	1.08
Sample Variance	20.94		Sample Variance	1.18
Kurtosis	-1.44		Kurtosis	2.43
Skewness	0.62		Skewness	1.08
Range	13.72		Range	6.44
Minimum	9.38		Minimum	9.38
Maximum	23.10		Maximum	15.83
Sum	2676.50		Sum	1372.43
Count	184.00		Count	121.00

The researcher then created a table similar to Table 5 above. In the cell containing the baseline time of day for July, the researcher multiplied the fuel consumed during the four-hour flight by the average amount of flights for July each year, to equal the average amount of fuel consumed at that baseline time each year. The average amount of fuel consumed at other hours of the day in July were then subtracted from the average amount of fuel consumed at the baseline time, to provide the differences in fuel consumed by shifting the baseline time earlier or later in the day. This process was accomplished for the other months of the year, and columns were created to display total annual savings in fuel and cost, and savings per flight in fuel and cost, that could be realized by shifting training flights at Charleston AFB earlier or later in the day. The

researcher created this table so that C-17 flight schedulers at Charleston AFB could have visibility of how efficiently they are scheduling flights, and see how much fuel they could save by flying at different times of the day.

Assumptions and Limitations

This research assumes that the information provided by Weather Underground, CFPS, and the AMC Fuel Efficiency Office's Air Force Fuel Tracker is correct and accurate. Additionally, this research assumes the results of the Charleston AFB temperature regression equations are representative of the temperatures the aircrews actually experienced, and the temperatures aircrews will experience during future flights. The researcher also assumes that future airland training flights at Charleston AFB will continue to approximate four hours in duration.

The amount of historical records contained in the AMC Fuel Efficiency Office's Air Force Fuel Tracker is extensive, and time constraints prevented analysis of it all. The researcher selected a specific aircraft (C-17), short time period (October 2010 through April 2014), location (Charleston AFB), and flight type (training flights) to demonstrate the potential savings across the entire year for all C-17 training flights, and ultimately all C-17 flight types in general. While the results demonstrate past savings for C-17 training flights at Charleston AFB, the model should serve as a framework to calculate potential savings for all AMC aircraft and flight types.

The models presented in this methodology also assume that the density of JP-8 fuel remains constant with a conversion factor of 6.7 pounds per gallon. Fuel density normally changes with temperature, and this assumption falls within the acceptable JP-8 product range of 6.4521 and 6.9941 pounds per gallon. The price point at Charleston

AFB for JP-8 was $3.70 per gallon, which equates to the standard fuel price in dollars for Fiscal Year 2015 according to DLA-Energy.

A limitation of this research is that the AMC Fuel Efficiency Office's Air Force Fuel Tracker data does not isolate other factors that affect fuel consumption. Examples of these factors include altitudes flown (planned and actual), winds at flight level, and the way the pilots actually flew the aircraft (excess angles of bank, inefficient climb and descent schedules, and inefficient airspeeds for example). Due to this lack of information, this research assumes optimally planned and flown flights.

IV. Analysis and Results

Starting with 153,501 C-17 flights, and examining 3,007 C-17 training flights at Charleston AFB, the results highlight that shifting the baseline time earlier or later in the day would save fuel. Tables 7 and 8 show the historical data results.

Table 7 assumes that the evening flights with midpoint flight times after 4:00 PM were scheduled well past the hottest time of the day, and shifting the baseline for those flights would have little effect. This table focused on the flights with midpoint flight times between 7:00 AM and 4:00 PM. The baseline times of day for those flights fell between 11:05 AM and 11:56 PM for each month, and are highlighted yellow on the table. Since the baseline times of day for those flights is prior to the hottest time of day, shifting the baseline times earlier results in increased fuel savings until reaching 5:00 AM or 6:00 AM, each month's coldest time of day. The green numbers in each monthly column are the potential monthly fuel savings (pounds) if the average amount of flights each month remains true, and the green numbers in the fuel savings column are the potential annual fuel savings if the annual baseline time of day shifts to that time. Also included in Table 7 are potential fuel savings per flight, potential annual cost savings (dollars), and potential cost savings per flight. Note that shifting the baseline time of these flights earlier to 5:00 AM yields the greatest annual fuel savings, at 241,959 pounds of fuel ($133,619).

Table 7. Fuel and Cost Savings by Shifting Flights between 7:00 AM and 4:00 PM

	January	February	March	April	May	June	July	August	September	October	November	December
12:00 AM	19,056	20,762	18,364	11,417	18,211	12,113	9,435	9,871	8,681	12,403	15,052	15,988
1:00 AM	19,609	21,591	19,655	12,893	20,813	13,863	10,677	11,181	9,446	13,374	16,101	16,790
2:00 AM	20,703	22,623	20,965	14,409	23,265	15,608	11,939	12,524	10,369	14,549	17,384	17,940
3:00 AM	22,317	23,839	22,322	15,921	25,332	17,182	13,100	13,810	11,414	15,971	18,766	19,316
4:00 AM	24,118	24,986	23,554	17,219	26,682	18,301	13,941	14,831	12,396	17,437	19,944	20,590
5:00 AM	25,535	25,635	24,319	17,964	26,964	18,638	14,203	15,300	13,022	18,538	20,524	21,316
6:00 AM	25,926	25,306	24,200	17,785	25,906	17,905	13,658	14,935	12,971	18,772	20,136	21,054
7:00 AM	24,758	23,619	22,832	16,388	23,396	15,952	12,181	13,543	11,996	17,692	18,541	19,508
8:00 AM	21,788	20,424	20,026	13,660	19,549	12,828	9,802	11,096	10,002	15,053	15,726	16,629
9:00 AM	17,158	15,881	15,861	9,731	14,712	8,804	6,728	7,763	7,103	10,916	11,937	12,661
10:00 AM	11,406	10,470	10,704	4,985	9,421	4,339	3,313	3,902	3,613	5,675	7,643	8,113
11:00 AM	5,368	4,906	5,168	2,528,090	4,311	2,828,621	2,465,456	2,687,356	2,212,626	2,740,126	3,457	3,660
12:00 PM	2,998,753	2,991,543	2,908,123	-4,558	3,107,123	-3,645	-2,768	-3,419	-3,209	-5,289	2,139,787	2,393,316
1:00 PM	-3,832	-3,514	-4,072	-8,065	-3,019	-6,137	-4,633	-5,896	-5,539	-9,397	-2,224	-2,299
2:00 PM	-5,546	-5,134	-6,483	-10,067	-4,469	-7,214	-5,391	-7,132	-6,669	-11,719	-2,937	-2,921
3:00 PM	-4,968	-4,697	-6,953	-10,368	-4,318	-6,850	-5,028	-7,036	-6,493	-11,975	-2,138	-1,868
4:00 PM	-2,364	-2,406	-5,530	-9,055	-2,768	-5,244	-3,705	-5,740	-5,138	-10,254	-90	556
5:00 PM	1,643	1,234	-2,567	-6,468	-182	-2,760	-1,716	-3,546	-2,923	-6,981	2,754	3,825
6:00 PM	6,232	5,539	1,367	-3,102	3,008	170	594	-855	-276	-2,807	5,868	7,326
7:00 PM	10,586	9,813	5,633	506	6,403	3,146	2,904	1,932	2,371	1,552	8,776	10,507
8:00 PM	14,084	13,499	9,657	3,902	9,715	5,881	4,989	4,502	4,679	5,481	11,158	12,997
9:00 PM	16,430	16,291	13,051	6,799	12,802	8,247	6,748	6,682	6,464	8,594	12,904	14,674
10:00 PM	17,683	18,165	15,670	9,116	15,661	10,267	8,209	8,454	7,725	10,790	14,110	15,662
11:00 PM	18,204	19,342	17,595	10,948	18,371	12,066	9,480	9,922	8,604	12,232	15,009	16,258

	Fuel Savings	Fuel Savings/Flight	$ Savings	$ Savings/Flight
12:00 AM	171,352	324	$94,627	$179.14
1:00 AM	185,993	352	$102,713	$194.44
2:00 AM	202,276	383	$111,704	$211.47
3:00 AM	219,289	415	$121,100	$229.25
4:00 AM	233,998	443	$129,223	$244.63
5:00 AM	241,959	458	$133,619	$252.95
6:00 AM	238,553	452	$131,738	$249.39
7:00 AM	220,405	417	$121,716	$230.42
8:00 AM	186,583	353	$103,039	$195.06
9:00 AM	139,256	264	$76,902	$145.58
10:00 AM	83,586	158	$46,159	$87.38
11:00 AM	26,871	51	$14,839	$28.09
12:00 PM	-22,887	-43	-$12,639	-$23.93
1:00 PM	-58,627	-111	-$32,376	-$61.29
2:00 PM	-75,682	-143	-$41,795	-$79.12
3:00 PM	-72,692	-138	-$40,144	-$76.00
4:00 PM	-51,738	-98	-$28,572	-$54.09
5:00 PM	-17,687	-33	-$9,767	-$18.49
6:00 PM	23,064	44	$12,737	$24.11
7:00 PM	64,130	121	$35,415	$67.04
8:00 PM	100,543	190	$55,524	$105.11
9:00 PM	129,686	246	$71,618	$135.58
10:00 PM	151,510	287	$83,670	$158.39
11:00 PM	168,033	318	$92,794	$175.67

Table 8 assumes that shifting the baseline time of day for all 3,007 C-17 training flights, not just the ones between 7:00 AM and 4:00 PM, results in increased fuel savings. The baseline times of day for all flights fell between 2:26 PM and 3:20 PM for each month, and are highlighted yellow on the table. Since the baseline times of day for those

flights is coincident with the hottest times of day, shifting the baseline times earlier or later results in increased fuel savings until reaching 5:00 AM or 6:00 AM, each month's coldest time of day. The green numbers in each column indicate the same potential fuel and cost savings as in Table 7. Note that shifting the baseline time of these flights earlier to 5:00 AM yields the greatest annual fuel savings, at 498,686 pounds of fuel ($275,394).

Looking at Table 7 above, shifting the baseline time of C-17 training flights between 7:00 AM and 4:00 PM to 5:00 AM achieves the greatest annual fuel savings. By shifting to this extreme, there would essentially be two night flights each day; one in the early morning and one at its normal evening time, leaving a large period of time in between flights. In comparison, shifting the baseline time of all C-17 training flights to 5:00 AM achieves the greatest annual fuel savings in Table 8. By shifting all flights nine to ten hours earlier to this extreme, there will still be a day flight and a night flight; the night flight will occur early in the morning and the day flight will occur around 10:00 AM, leaving the same times in between flights as before. While the results of Table 8 yield twice the potential fuel and cost savings as the results of Table 7, which solution is better? The next section will discuss conclusions and recommendations for this research.

Table 8. Fuel and Cost Savings by Shifting All Flights

	January	February	March	April	May	June	July	August	September	October	November	December
12:00 AM	37,479	38,765	40,796	33,705	35,926	28,376	21,994	27,924	24,922	39,599	26,632	30,545
1:00 AM	38,341	40,027	42,876	36,021	40,076	30,995	23,882	30,088	26,179	41,175	28,257	31,918
2:00 AM	40,047	41,598	44,987	38,399	43,987	33,606	25,802	32,305	27,695	43,083	30,245	33,885
3:00 AM	42,565	43,450	47,174	40,772	47,282	35,961	27,566	34,430	29,412	45,393	32,386	36,239
4:00 AM	45,374	45,196	49,159	42,808	49,435	37,637	28,845	36,116	31,024	47,775	34,211	38,419
5:00 AM	47,586	46,184	50,391	43,977	49,886	38,141	29,245	36,891	32,051	49,564	35,111	39,661
6:00 AM	48,194	45,684	50,200	43,696	48,197	37,044	28,416	36,288	31,968	49,944	34,508	39,213
7:00 AM	46,373	43,116	47,995	41,505	44,195	34,121	26,169	33,989	30,366	48,189	32,037	36,568
8:00 AM	41,739	38,250	43,474	37,225	38,061	29,446	22,552	29,948	27,092	43,903	27,677	31,643
9:00 AM	34,517	31,334	36,762	31,061	30,347	23,425	17,877	24,443	22,329	37,183	21,806	24,855
10:00 AM	25,545	23,095	28,452	23,615	21,910	16,743	12,684	18,066	16,597	28,669	15,154	17,075
11:00 AM	16,125	14,623	19,532	15,794	13,760	10,250	7,646	11,621	10,664	19,452	8,668	9,457
12:00 PM	7,751	7,152	11,204	8,644	6,886	4,796	3,436	5,975	5,394	10,861	3,312	3,196
1:00 PM	1,772	1,802	4,643	3,142	2,071	1,066	600	1,883	1,566	4,189	-133	-737
2:00 PM	-901	-664	757	3,982,019	-240	-545	-553	-157	-289	416	-1,238	-1,802
3:00 PM	4,685,806	4,562,115	4,697,351	-472	4,961,833	4,243,108	3,756,875	4,450,033	3,644,778	4,470,265	3,318,475	4,097,422
4:00 PM	4,063	3,489	2,294	1,587	2,472	2,403	2,011	2,142	2,225	2,796	3,173	4,146
5:00 PM	10,314	9,031	7,067	5,647	6,596	6,120	5,037	5,765	5,862	8,112	7,579	9,739
6:00 PM	17,472	15,587	13,407	10,928	11,682	10,504	8,549	10,209	10,211	14,892	12,403	15,729
7:00 PM	24,265	22,094	20,281	16,588	17,096	14,957	12,062	14,812	14,559	21,972	16,909	21,170
8:00 PM	29,722	27,707	26,765	21,915	22,378	19,051	15,232	19,056	18,348	28,355	20,599	25,429
9:00 PM	33,381	31,957	32,235	26,461	27,301	22,591	17,908	22,657	21,281	33,411	23,305	28,298
10:00 PM	35,337	34,811	36,455	30,095	31,861	25,614	20,129	25,584	23,351	36,977	25,172	29,988
11:00 PM	36,149	36,603	39,557	32,971	36,182	28,306	22,062	28,008	24,796	39,321	26,565	31,008

	Fuel Savings	Fuel Savings/Flight	$ Savings	$ Savings/Flight
12:00 AM	386,663	462	$213,530	$254.87
1:00 AM	409,836	489	$226,327	$270.14
2:00 AM	435,638	520	$240,576	$287.15
3:00 AM	462,631	552	$255,483	$304.94
4:00 AM	486,000	580	$268,388	$320.35
5:00 AM	498,686	595	$275,394	$328.71
6:00 AM	493,352	589	$272,448	$325.19
7:00 AM	464,623	555	$256,583	$306.26
8:00 AM	411,009	491	$226,975	$270.92
9:00 AM	335,940	401	$185,519	$221.44
10:00 AM	247,607	296	$136,738	$163.21
11:00 AM	157,593	188	$87,029	$103.88
12:00 PM	78,606	94	$43,409	$51.81
1:00 PM	21,864	26	$12,074	$14.41
2:00 PM	-5,218	-6	-$2,881	-$3.44
3:00 PM	-472	-1	-$261	-$0.31
4:00 PM	21,375	26	$11,804	$14.09
5:00 PM	86,869	104	$47,973	$57.26
6:00 PM	151,573	181	$83,705	$99.91
7:00 PM	216,767	259	$119,707	$142.88
8:00 PM	274,558	328	$151,621	$180.98
9:00 PM	320,785	383	$177,150	$211.45
10:00 PM	355,373	424	$196,251	$234.25
11:00 PM	381,529	455	$210,695	$251.49

V. Conclusions and Recommendations

Conclusions of Research

The USAF is the largest user of aviation fuel in the DoD, and air mobility operations consume the greatest amount. AMC has made considerable improvements to support the Air Force Energy Strategic Plan for a 10 percent efficiency improvement by the year 2020, but was in search of the cause for decreased fuel efficiency during the summer months of June through August. This research hypothesized that AMC is not scheduling flights during the optimal times of the day to minimize fuel consumption, and that there is a potential for significant cost savings within AMC and the USAF by making a concerted effort to shift flight times away from the hottest times of the day. Indeed, temperature's effect on fuel consumption was missing from the equations.

From a temperature standpoint, the optimal times during the day to schedule flights to minimize fuel consumption are when the temperatures are coolest. In general, 5:00 AM is the most optimal time of the day to schedule a C-17 flight at Charleston AFB, and 2:00 PM is the least optimal time. On average, 603 pounds of fuel (90 gallons) are saved by shifting the midpoint time of a four-hour C-17 training flight from the least optimal time to the most optimal time, and an annual fuel savings of 498,686 pounds of fuel ($275,394) could be realized by shifting the baseline time of 3,007 selected C-17 flights to this time. Extrapolated to the 6,516 C-17 training flights operated by the 315th and 437th AWs at Charleston AFB between October 2010 and April 2014, the potential exists to save 3,878,537 pounds of fuel ($2,141,878) over the same time

period by shifting the baseline to this time, the equivalent of the fuel required for 65 four-hour training flights.

At Charleston AFB, the optimal times during the day to schedule flights to minimize fuel consumption are also affected by month of the year. Generally, January is the most optimal month of the year to schedule a C-17 flight at Charleston AFB, and July is the least optimal month. On average, 1,279 pounds of fuel (191 gallons) are saved by shifting the midpoint time of a four-hour C-17 training flight in July to the same time in January. Additionally, a maximum of 1,809 pounds of fuel (270 gallons) are saved by shifting the midpoint time from the least optimal time in July to the most optimal time in January. Finally, an average of 1,028 pounds of fuel (153 gallons) are saved by shifting the midpoint time from the most optimal time between May and August to the most optimal time between November and February; 940 pounds of fuel (140 gallons) are saved by shifting the midpoint time from the least optimal times of those same months. With the hypothesis and research questions answered, recommendations for policy options will be addressed next.

Recommendations for Policy Options

It is imperative that Charleston AFB alter its training flight schedules to increase fuel efficiency and reduce fuel consumption. Recommendations for policy options include decreasing the amount of day training flights and increasing the amount of night training flights, decreasing the amount of summer training flights (May through August) and increasing the amount of winter training flights (November through February), and applying a similar methodology to ALL flights originating from Charleston AFB.

If the decision is made to shift the baseline time of all C-17 training flights to 5:00 AM for maximum savings, the average midpoint time of the day flights would shift to approximately 1:20 AM and the average midpoint time of the night flights would shift to approximately 10:00 AM. There would still be day flights and night flights each day, and the main difference is that the amount of night flights increases two-fold. Night flying is inherently more difficult than day flying, and the opportunity for increased night flights would help to improve aircrew familiarity and proficiency. Additionally, many C-17 training events accomplished at night are able to be "dual-logged" for the corresponding day events; increasing the amount of training at night decreases the amount of flights required for each pilot and loadmaster, further reducing fuel consumption. However, a disadvantage of shifting the baseline time of all C-17 training flights to the optimal time concerns Operational Risk Management (ORM). On average, the show time for the night flights would be approximately 8:35 PM and the show time for the day flights would be approximately 5:15 AM. Both of these show times fall in the "high" risk category, requiring squadron commander approval to execute. Risks must be mitigated whenever possible, so unless aircrew circadian rhythms are aligned for night operations, a shift to a show time prior to 8:00 PM and after 5:30 AM would be preferred for a slight reduction in savings.

C-17 pilots and loadmasters must accomplish numerous monthly, quarterly, and semi-annual training events, and AW training flight hours are allocated to accomplish them. The majority of the training events are required semi-annually, yet the average amount of Charleston AFB training flights per month is similar. Every summer training flight (May through August) that is shifted to the winter months (November through

February) saves approximately 1,000 pounds of fuel (approximately 150 gallons), with a maximum of 1,809 pounds of fuel (270 gallons) saved by shifting the midpoint time from the least optimal time in July to the most optimal time in January. The decision to decrease the amount of summer training flights and increase the amount of winter training flights would significantly reduce fuel consumption, yet allow completion of semi-annual training events at the beginning of the first semi-annual period and the end of the second semi-annual period. That said, summer training flights cannot be completely removed, as a small amount are needed to accomplish flight evaluations, as well as monthly and last minute semi-annual training events. The fuel savings would be exponentially increased if combined with a shift in baseline time towards the most optimal time of the day.

Perhaps the greatest amount of fuel savings can be realized when applying a similar methodology to ALL flights departing from Charleston AFB. The researcher planned a climb out from Charleston AFB to 30,000 feet using CFPS. C-17A was the selected aircraft, the aircraft had 100,000 pounds of fuel at takeoff, the climb was planned using calm winds, and a decrease of two degrees Celsius per 1,000 feet of altitude was assumed. Figure 19 below displays the fuel consumed when departing with zero cargo, 50,000 pounds of cargo, 100,000 pounds of cargo, and 150,000 pounds of cargo, for temperatures between -5 degrees Celsius and 35 degrees Celsius. Between 283 and 603 pounds of fuel (42 – 90 gallons) are saved in January by shifting the departure time from the least optimal time to the most optimal time, and 979 – 2723 pounds of fuel (146 – 406 gallons) are saved in July by shifting the departure time from the least optimal time to the most optimal time. 2,896 C-17 Channel, Contingency, and SAAM flights departed from

Charleston AFB between October 2010 and April 2014, and careful planning of the departure times by the Tanker Airlift Control Center would reduce fuel consumption by thousands, if not millions, of pounds.

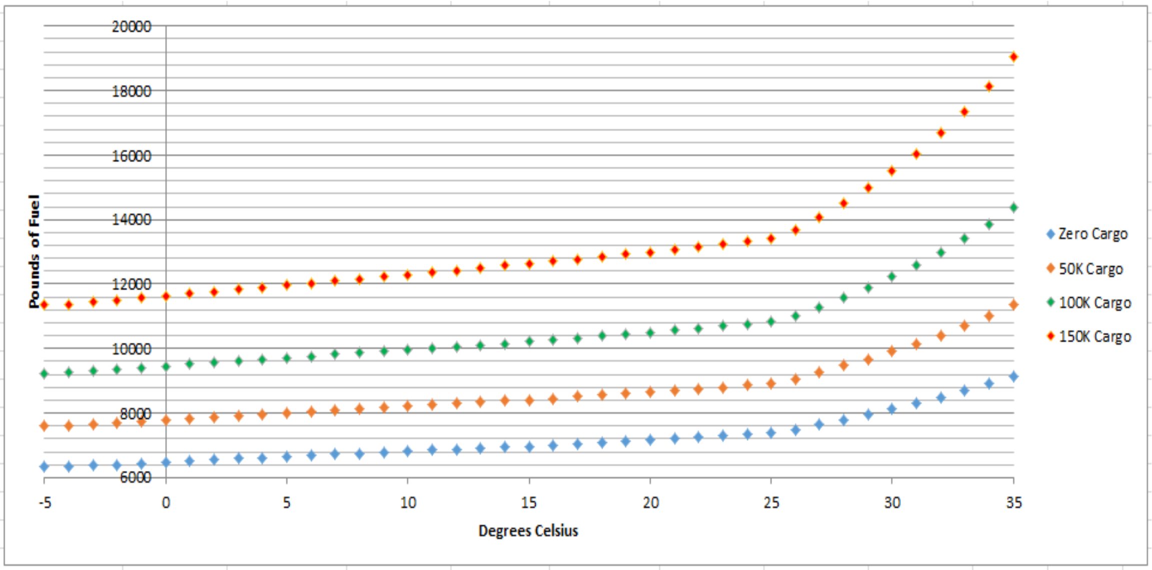


Figure 19. Fuel Consumed During Climb to 30,000 Feet

<u>Additional Recommendations</u>

A few additional recommendations to increase fuel efficiency and reduce fuel consumption are worth mentioning. First, flight planners and aircrews must be allowed some flexibility to adjust flights on short notice to consume less fuel. They need to keep an eye on upcoming weather patterns from AFWA, Weather Underground, or CFPS within 96 hours, and have the ability to shift flights away from upcoming warm fronts, cold fronts, etc. Ideally, refinements to the coming week's schedule would be negotiated during the 437th/315th AW Weekly Operations Group and Maintenance Group Meeting.

Second, the 437th/315th AW should utilize off-station trainers (OST) to the maximum extent possible, and especially during the summer months when temperatures at Charleston AFB are highest. OSTs are active duty and reserve training lines in which squadrons operate training tails outside of the local pattern area, and count against an AW's training allocations. The decision to operate training flights from a cooler location would reduce fuel consumption, and afford aircrews the opportunity to gain experience at a less familiar location with unique training opportunities.

Recommendations for Future Research

In order to realize the greatest gains in fuel efficiency and reductions in fuel consumption, ORM factors must be mitigated. The first idea for future research involves a study of "Home Station Show Time" ORM risk definitions. Specifically, why is a show time of 5:29 AM defined as "high" risk, while a show time of 5:31 AM is "low" risk? If pilots and loadmasters are afforded adequate time for crew rest and can assess their sleep as restful, it is arguable that they have successfully mitigated the risk. The line has to drawn somewhere, but there may be a better way to define it.

Second, while Charleston AFB was the focus of this research, there is a likely potential for similar cost savings at other C-17 bases. A similar methodology must be applied at other C-17 bases to determine the optimal times of day and months of the year to schedule C-17 flights. Extrapolating the results from the 3,007 C-17 training flights at Charleston AFB between October 2010 and April 2014 to the 24,581 total C-17 training flights during the same period, the potential exists to save 14,631,417 pounds of fuel ($8,080,036) by shifting the baseline to the most optimal time, the equivalent of the fuel required for 244 four-hour training flights. Additionally, a look into the

departure times of Channel, Contingency, and SAAM flights at all locations is warranted for increased fuel savings.

Finally, the applications of the methodology contained in this research is not limited only the C-17. Temperature affects the performance of all aircraft, and applying this methodology to all AMC-operated aircraft would significantly increase fuel efficiency and reduce fuel consumption.

Implications

This research could result in an institutional savings of millions of pounds of fuel and dollars for the USAF. It provides a methodology to identify the optimal times during the day to schedule flights to minimize fuel consumption, and the effect that month of the year has on these times. Flying during cooler times of the day reduces CFL required for takeoff, increases the ability to carry more cargo, increases rate of climb, increases overall aircraft performance for desired maneuvers, and shortens the runway length required for landing. If AMC's concern is for operations to be as *efficient* as effectiveness allows, it will institutionalize the recommendations of this research. By adjusting flight schedules to take advantage of temperature effects, AMC will be one-step closer to the USAF's primary energy goal of a 10 percent improvement by the year 2020.

Appendix A: C-17 Regression Equations

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.987313553
R Square	0.974788052
Adjusted R Square	0.974779305
Standard Error	6635.313684
Observations	14418

ANOVA

	df	SS	MS	F	Significance F
Regression	5	2.4533E+13	4.91E+12	111444.3	0
Residual	14412	6.34523E+11	44027388		
Total	14417	2.51675E+13			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2154.153036	207.4058852	10.38617	3.52E-25	1747.610829	2560.695244	1747.610829	2560.695244
Weight	41.73503266	5.869048609	7.111039	1.21E-12	30.23094261	53.2391227	30.23094261	53.2391227
Weight^2	-0.280165884	0.047724901	-5.87043	4.44E-09	-0.373712828	-0.18661894	-0.373712828	-0.18661894
Time	16558.40923	84.78116031	195.3077	0	16392.22726	16724.59121	16392.22726	16724.59121
Time^2	-87.62754657	8.551440651	-10.2471	1.48E-24	-104.38947	-70.8656232	-104.38947	-70.86562316
Weight * Time	41.55572129	0.914165977	45.45752	0	39.76383841	43.34760417	39.76383841	43.34760417

Figure 20. C-17 Channel Flights (HQ AMC, 2014)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.992245606
R Square	0.984551343
Adjusted R Square	0.984540346
Standard Error	7384.914722
Observations	7030

ANOVA

	df	SS	MS	F	Significance F
Regression	5	2.44131E+13	4.88E+12	89528.67	0
Residual	7024	3.83068E+11	54536965		
Total	7029	2.47962E+13			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	707.9436759	206.8105356	3.423151	0.000623	302.5326149	1113.354737	302.5326149	1113.354737
Weight	67.29121684	8.328720004	8.079419	7.6E-16	50.9644122	83.61802149	50.9644122	83.61802149
Weight^2	-0.561246696	0.095722896	-5.86324	4.74E-09	-0.748892461	-0.37360093	-0.748892461	-0.373600932
Time	16414.86997	86.59777706	189.553	0	16245.11219	16584.62775	16245.11219	16584.62775
Time^2	-27.79590823	8.207451064	-3.38667	0.000711	-43.88498916	-11.7068273	-43.88498916	-11.7068273
Weight * Time	30.13498516	1.019614189	29.55528	4.7E-181	28.13623365	32.13373667	28.13623365	32.13373667

Figure 21. C-17 SAAM Flights (HQ AMC, 2014)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.988646864
R Square	0.977422621
Adjusted R Square	0.977415557
Standard Error	6993.837495
Observations	15986

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	3.38389E+13	6.77E+12	138361.6	0
Residual	15980	7.81642E+11	48913763		
Total	15985	3.46206E+13			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2587.075862	180.8416449	14.30575	3.88E-46	2232.605903	2941.545822	2232.605903	2941.545822
Weight	71.73709354	5.709606232	12.56428	4.91E-36	60.54562329	82.92856379	60.54562329	82.92856379
Weight ^2	-0.265872076	0.049049272	-5.42051	6.03E-08	-0.362014164	-0.16972999	-0.362014164	-0.169729987
Time	16263.848	75.57875213	215.1907	0	16115.70515	16411.99086	16115.70515	16411.99086
Time^2	-33.3730851	7.119207526	-4.68775	2.79E-06	-47.32753239	-19.4186378	-47.32753239	-19.41863781
Weight * Time	28.37112625	0.738415069	38.42165	0	26.92374968	29.81850282	26.92374968	29.81850282

Figure 22. C-17 Contingency Flights (HQ AMC, 2014)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.976779052
R Square	0.954097316
Adjusted R Square	0.954065798
Standard Error	6609.376963
Observations	7288

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	6.6119E+12	1.32E+12	30271.59	0
Residual	7282	3.18106E+11	43683864		
Total	7287	6.93001E+12			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2300.687442	257.7676032	8.925433	5.54E-19	1795.388236	2805.986647	1795.388236	2805.986647
Weight	-154.9259764	18.00945338	-8.60248	9.45E-18	-190.2297243	-119.622228	-190.2297243	-119.6222284
Weight ^2	2.040712404	0.278329975	7.331989	2.51E-13	1.495104989	2.586319819	1.495104989	2.586319819
Time	18077.28314	133.1706205	135.7453	0	17816.23013	18338.33615	17816.23013	18338.33615
Time^2	-165.3475498	17.55195918	-9.42046	5.91E-21	-199.7544765	-130.940623	-199.7544765	-130.9406231
Weight * Time	22.27828548	2.904105144	7.671308	1.92E-14	16.58539776	27.9711732	16.58539776	27.9711732

Figure 23. C-17 Training Flights (HQ AMC, 2014)

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.993711818							
R Square	0.987463177							
Adjusted R Square	0.987237695							
Standard Error	6726.437482							
Observations	284							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	5	9.90714E+11	1.98E+11	4379.335	5.4528E-262			
Residual	278	12578099215	45244961					
Total	283	1.00329E+12						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	996.3536747	1114.432326	0.894046	0.372071	-1197.444222	3190.151571	-1197.444222	3190.151571
Weight	15.13894951	61.97966059	0.244257	0.807212	-106.8701181	137.1480171	-106.8701181	137.1480171
Weight ^2	-0.363763458	0.728391472	-0.49941	0.617888	-1.797626818	1.070099902	-1.797626818	1.070099902
Time	15847.05779	316.9966358	49.99125	5.8E-141	15223.03915	16471.07644	15223.03915	16471.07644
Time^2	45.0225412	24.61468529	1.829093	0.068457	-3.432303073	93.47738548	-3.432303073	93.47738548
Weight * Time	33.51618333	4.882078982	6.865146	4.33E-11	23.90564499	43.12672167	23.90564499	43.12672167

Figure 24. C-17 Exercise Flights (HQ AMC, 2014)

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.9921112							
R Square	0.984284633							
Adjusted R Square	0.984194211							
Standard Error	5805.88519							
Observations	875							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	5	1.83465E+12	3.67E+11	10885.44	0			
Residual	869	29292515166	33708303					
Total	874	1.86394E+12						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3597.174721	505.6405488	7.114095	2.36E-12	2604.755224	4589.594219	2604.755224	4589.594219
Weight	-50.80906753	29.97608257	-1.69499	0.090436	-109.6430532	8.024918152	-109.6430532	8.024918152
Weight ^2	0.752237478	0.450662826	1.66918	0.095442	-0.132277375	1.636752332	-0.132277375	1.636752332
Time	15148.61156	252.569462	59.978	0	14652.89408	15644.32904	14652.89408	15644.32904
Time^2	113.7576699	25.47704521	4.465105	9.06E-06	63.7539341	163.7614057	63.7539341	163.7614057
Weight * Time	30.80658102	3.437596361	8.961663	1.92E-18	24.05961885	37.55354319	24.05961885	37.55354319

Figure 25. C-17 Other Flights (HQ AMC, 2014)

Appendix B: Charleston AFB Temperature Regression Output

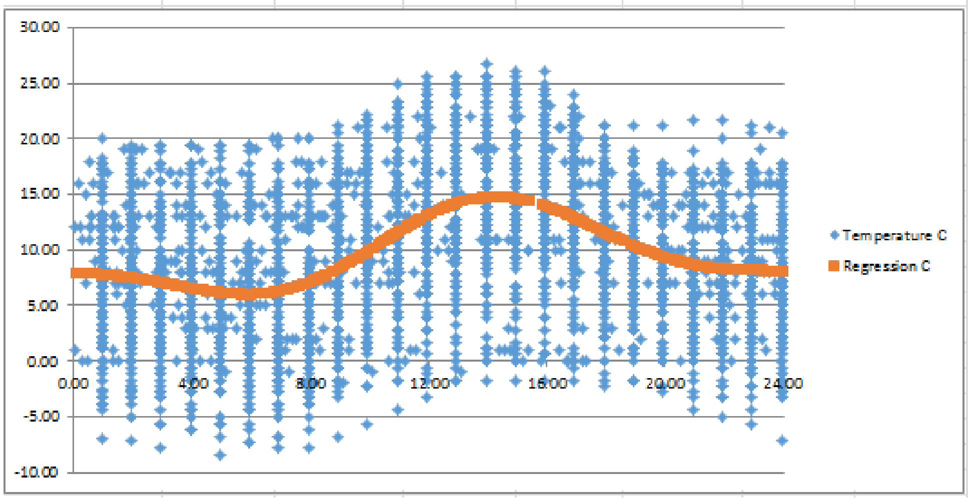
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.427069
R Square	0.182388
Adjusted R Square	0.1811792
Standard Error	5.9903189
Observations	3388

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	27072.12943	5414.4259	150.88724	5.367E-145
Residual	3382	121359.4208	35.883921		
Total	3387	148431.5502			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	9.7088907	0.388982429	24.959715	2.37E-126	8.94622619	10.471555	8.9462262	10.471555
Hour	0.0064034	0.030292572	0.2113851	0.8325995	-0.0529902	0.065797	-0.05299	0.065797
Sin(Pi*Hour/12)	-2.683969	0.273055067	-9.829406	1.679E-22	-3.2193387	-2.148599	-3.219339	-2.148599
Cos(Pi*Hour/12)	-2.595904	0.14754489	-17.59399	2.275E-66	-2.8851901	-2.306618	-2.88519	-2.306618
Sin(Pi*Hour/6)	1.1416101	0.186129149	6.1334301	9.594E-10	0.7766731	1.5065472	0.7766731	1.5065472
Cos(Pi*Hour/6)	0.9247379	0.147446914	6.2716667	4.024E-10	0.6356438	1.213832	0.6356438	1.213832



Min Regress	6.13
Max Regress	14.86
Difference	8.73
Difference/12	0.7274

Figure 26. January Charleston AFB Temperature Regression Output

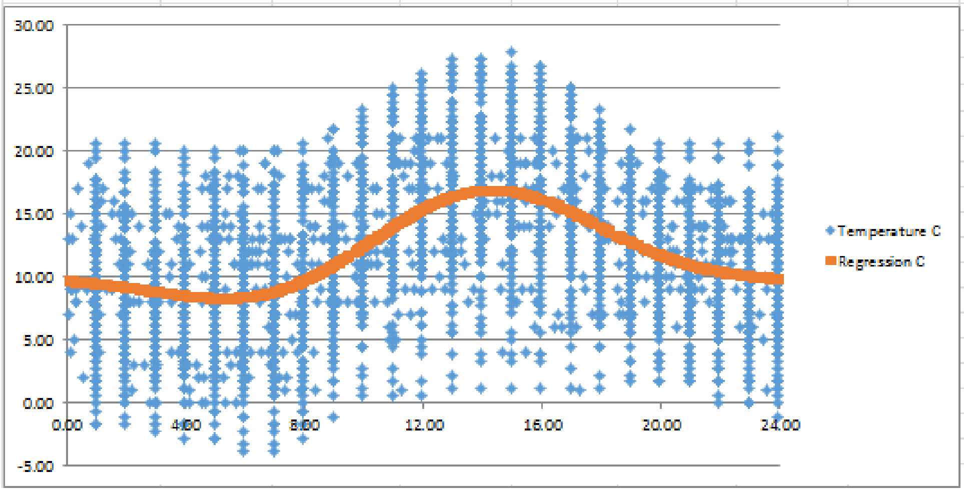
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.4994729
R Square	0.2494732
Adjusted R Square	0.2482789
Standard Error	5.0427959
Observations	3148

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	26558.6909	5311.7382	208.87856	9.295E-193
Residual	3142	79900.40309	25.429791		
Total	3147	106459.094			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	11.8227	0.342090692	34.560134	4.1E-222	11.1519562	12.493444	11.151956	12.493444
Hour	0.0068233	0.026701641	0.2555384	0.798324	-0.0455311	0.0591777	-0.045531	0.0591777
Sin(Pi*Hour/12)	-2.705326	0.23900155	-11.31928	3.833E-29	-3.173941	-2.236711	-3.173941	-2.236711
Cos(Pi*Hour/12)	-2.843618	0.129032869	-22.03794	3.35E-100	-3.0966153	-2.590621	-3.096615	-2.590621
Sin(Pi*Hour/6)	0.9256407	0.16220518	5.7066039	1.26E-08	0.60760189	1.2436795	0.6076019	1.2436795
Cos(Pi*Hour/6)	0.7209339	0.128179321	5.6244164	2.025E-08	0.4696102	0.9722575	0.4696102	0.9722575



Min Regress	8.34
Max Regress	16.92
Difference	8.58
Difference/12	0.715

Figure 27. February Charleston AFB Temperature Regression Output

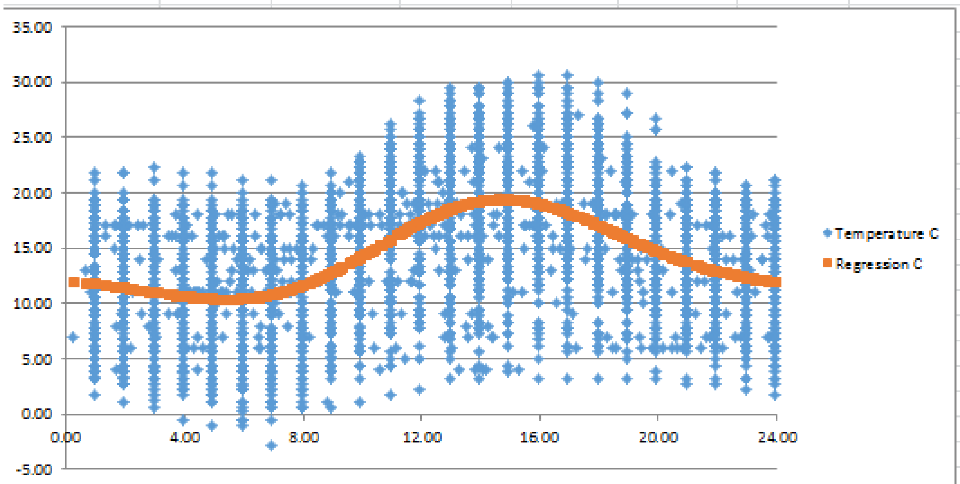
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.5004557
R Square	0.2504559
Adjusted R Square	0.2493202
Standard Error	5.3667303
Observations	3306

ANOVA

	df	SS	MS	F	Significance F
Regression	5	31759.05086	6351.8102	220.53523	1.651E-203
Residual	3300	95045.92094	28.801794		
Total	3305	126804.9718			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	14.339718	0.366253517	39.152436	9.88E-276	13.6216104	15.057825	13.62161	15.057825
Hour	-0.00837	0.028459162	-0.29409	0.7687075	-0.064169	0.0474298	-0.064169	0.0474298
Sin(Pi*Hour/12)	-3.320998	0.252593846	-13.14758	1.607E-38	-3.8162548	-2.825742	-3.816255	-2.825742
Cos(Pi*Hour/12)	-2.680874	0.134603252	-19.91686	1.925E-83	-2.9447884	-2.41696	-2.944788	-2.41696
Sin(Pi*Hour/6)	0.9449086	0.169634112	5.5702749	2.747E-08	0.61230989	1.2775074	0.6123099	1.2775074
Cos(Pi*Hour/6)	0.4908141	0.133743279	3.6698223	0.0002466	0.22858588	0.7530423	0.2285859	0.7530423



Min Regress	10.42
Max Regress	19.42
Difference	9.00
Difference/12	0.7498

Figure 28. March Charleston AFB Temperature Regression Output

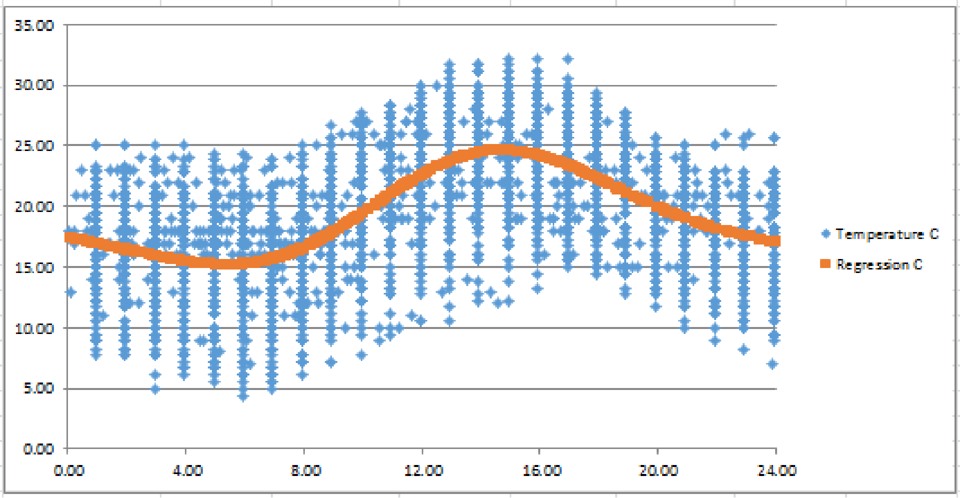
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6150257
R Square	0.3782566
Adjusted R Square	0.3772962
Standard Error	4.1250666
Observations	3243

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	33510.42721	6702.0854	393.86558	0
Residual	3237	55081.35691	17.016175		
Total	3242	88591.78412			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	19.647588	0.280839292	69.960255	0	19.0969476	20.198229	19.096948	20.198229
Hour	-0.014939	0.021896576	-0.682258	0.4951246	-0.0578717	0.0279934	-0.057872	0.0279934
Sin(Pi*Hour/12)	-3.547559	0.194726693	-18.21815	1.123E-70	-3.9293592	-3.165759	-3.929359	-3.165759
Cos(Pi*Hour/12)	-2.734273	0.104625874	-26.13381	9.17E-137	-2.9394122	-2.529133	-2.939412	-2.529133
Sin(Pi*Hour/6)	0.8638142	0.131328242	6.5775207	5.557E-11	0.60631933	1.1213091	0.6063193	1.1213091
Cos(Pi*Hour/6)	0.6028446	0.103581289	5.820014	6.459E-09	0.39975302	0.8059361	0.399753	0.8059361



Min Regress	15.33
Max Regress	24.76
Difference	9.43
Difference/12	0.7858

Figure 29. April Charleston AFB Temperature Regression Output

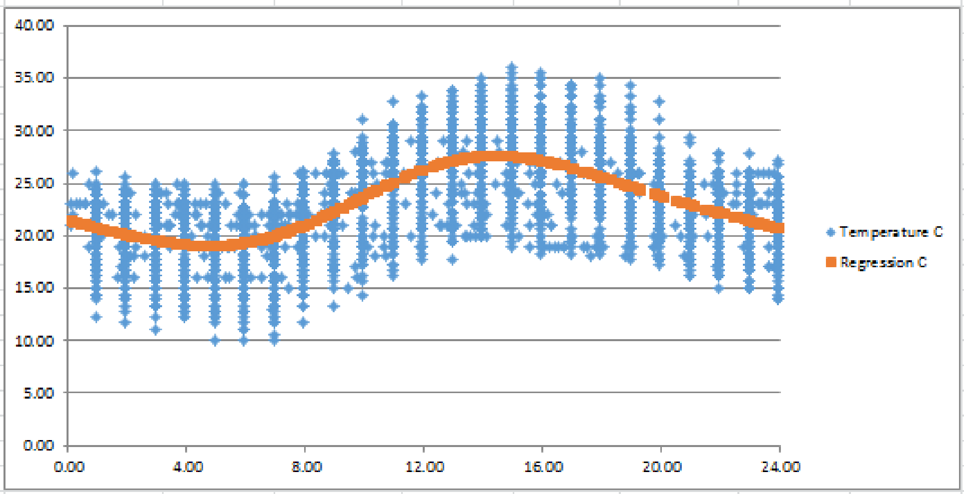
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6569356
R Square	0.4315643
Adjusted R Square	0.430686
Standard Error	3.3745664
Observations	3242

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	27977.48514	5595.497	491.36331	0
Residual	3236	36850.59128	11.387698		
Total	3241	64828.07642			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	23.516124	0.227580531	103.331	0	23.0699073	23.96234	23.069907	23.96234
Hour	-0.031714	0.017664035	-1.795416	0.0726807	-0.0663481	0.0029195	-0.066348	0.0029195
Sin(Pi*Hour/12)	-3.293539	0.158391411	-20.79367	3.056E-90	-3.6040962	-2.982981	-3.604096	-2.982981
Cos(Pi*Hour/12)	-2.658319	0.085229891	-31.18999	5.86E-187	-2.8254293	-2.491209	-2.825429	-2.491209
Sin(Pi*Hour/6)	0.3453532	0.10694722	3.2291932	0.0012538	0.13566211	0.5550444	0.1356621	0.5550444
Cos(Pi*Hour/6)	0.6301251	0.085039847	7.4097627	1.606E-13	0.46338769	0.7968625	0.4633877	0.7968625



Min Regress	19.10
Max Regress	27.67
Difference	8.57
Difference/12	0.7139

Figure 30. May Charleston AFB Temperature Regression Output

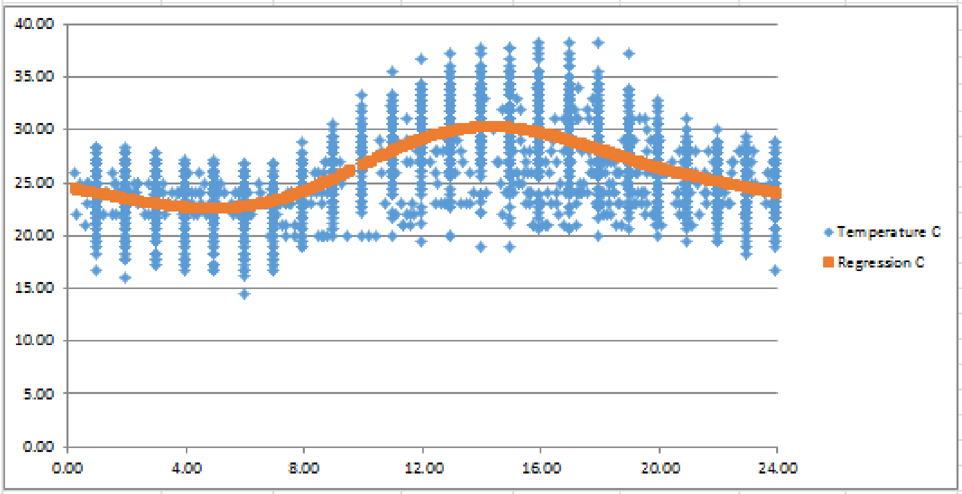
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6878596
R Square	0.4731508
Adjusted R Square	0.4723393
Standard Error	2.7646512
Observations	3252

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	22281.39894	4456.2798	583.03117	0
Residual	3246	24810.13883	7.643296		
Total	3251	47091.53777			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	26.426447	0.188351976	140.30353	0	26.0571464	26.795748	26.057146	26.795748
Hour	-0.02091	0.014683379	-1.424049	0.1545284	-0.0496995	0.0078798	-0.049699	0.0078798
Sin(Pi*Hour/12)	-2.771312	0.130549861	-21.22799	9.381E-94	-3.0272802	-2.515343	-3.02728	-2.515343
Cos(Pi*Hour/12)	-2.476304	0.070070252	-35.3403	9.38E-232	-2.6136901	-2.338917	-2.61369	-2.338917
Sin(Pi*Hour/6)	0.4384974	0.088080304	4.9783815	6.746E-07	0.26579874	0.611196	0.2657987	0.611196
Cos(Pi*Hour/6)	0.6539013	0.06956203	9.4002621	9.958E-21	0.51751138	0.7902912	0.5175114	0.7902912



Min Regress	22.65
Max Regress	30.38
Difference	7.73
Difference/12	0.6439

Figure 31. June Charleston AFB Temperature Regression Output

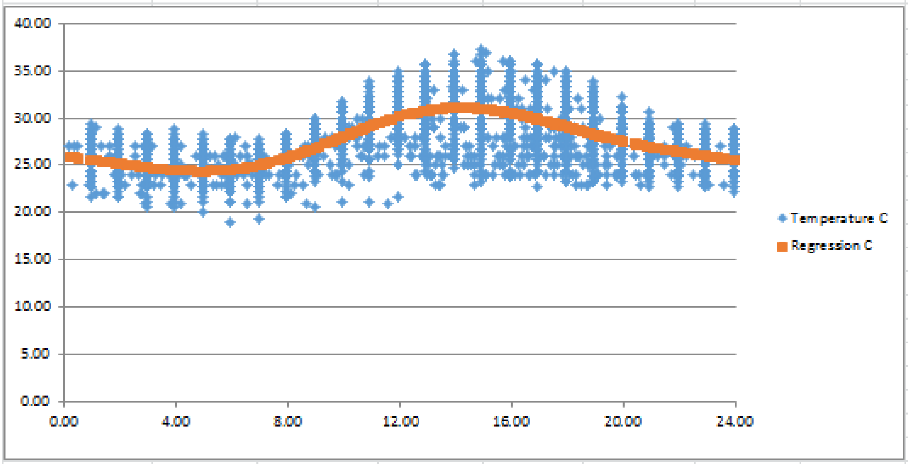
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7193131
R Square	0.5174113
Adjusted R Square	0.5166849
Standard Error	2.2147604
Observations	3328

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	17470.76113	3494.1522	712.34162	0
Residual	3322	16294.95358	4.9051636		
Total	3327	33765.71471			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	27.669524	0.151458458	182.68722	0	27.3725626	27.966485	27.372563	27.96648523
Hour	-0.017963	0.01181219	-1.520685	0.128434	-0.0411225	0.0051973	-0.041123	0.00519728
Sin(Pi*Hour/12)	-2.346744	0.10450895	-22.45496	4.4E-104	-2.5516523	-2.141835	-2.551652	-2.141835401
Cos(Pi*Hour/12)	-2.199213	0.05563396	-39.53005	1.93E-280	-2.3082938	-2.090133	-2.308294	-2.090133164
Sin(Pi*Hour/6)	0.4092379	0.06980763	5.862366	5.01E-09	0.27236757	0.5461082	0.2723676	0.546108186
Cos(Pi*Hour/6)	0.5961199	0.055136544	10.811702	8.42E-27	0.48801486	0.7042249	0.4880149	0.70422492



Min Regress	24.43
Max Regress	31.15
Difference	6.72
Difference/12	0.56030466

Figure 32. July Charleston AFB Temperature Regression Output

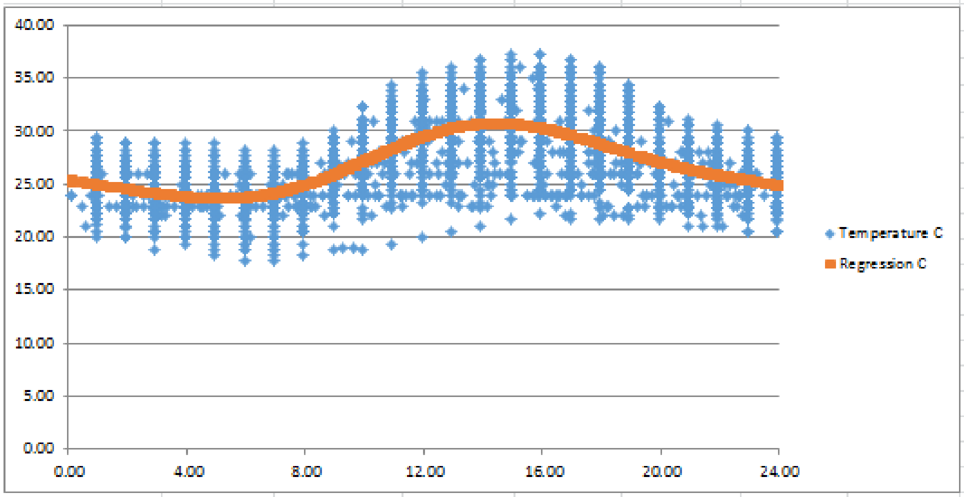
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.698817
R Square	0.4883452
Adjusted R Square	0.487577
Standard Error	2.469742
Observations	3336

ANOVA

	df	SS	MS	F	Significance F
Regression	5	19386.40741	3877.2815	635.65896	0
Residual	3330	20311.75242	6.0996254		
Total	3335	39698.15982			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	27.078192	0.169650829	159.61131	0	26.7455614	27.410822	26.745561	27.410822
Hour	-0.017976	0.013208396	-1.360968	0.173616	-0.0438736	0.0079212	-0.043874	0.0079212
Sin(Pi*Hour/12)	-2.588274	0.116794198	-22.16098	1.29E-101	-2.8172701	-2.359279	-2.81727	-2.359279
Cos(Pi*Hour/12)	-2.195456	0.061866406	-35.48705	3.01E-234	-2.3167561	-2.074156	-2.316756	-2.074156
Sin(Pi*Hour/6)	0.5485919	0.077879166	7.0441424	2.257E-12	0.39589608	0.7012878	0.3958961	0.7012878
Cos(Pi*Hour/6)	0.545205	0.061438252	8.8740326	1.129E-18	0.4247445	0.6656656	0.4247445	0.6656656



Min Regress	23.72
Max Regress	30.81
Difference	7.09
Difference/12	0.5905

Figure 33. August Charleston AFB Temperature Regression Output

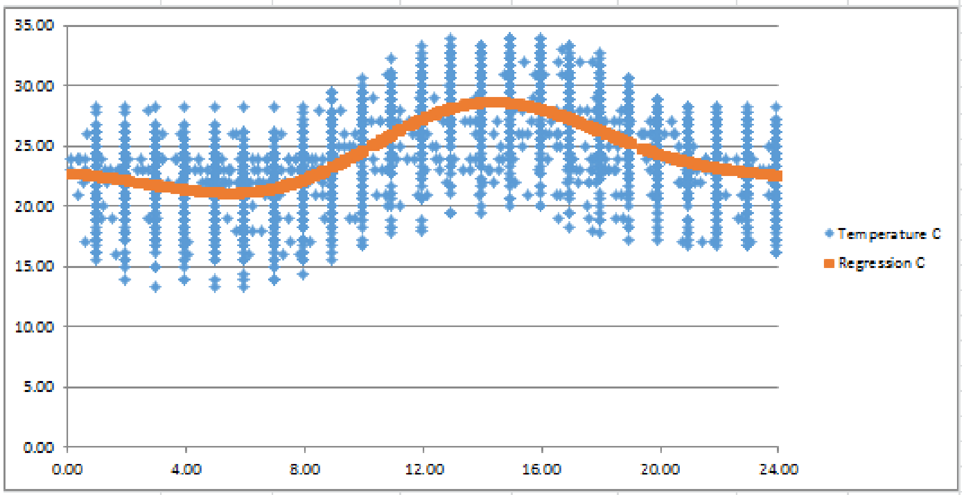
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6515667
R Square	0.4245392
Adjusted R Square	0.423647
Standard Error	2.9517719
Observations	3231

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	20729.90799	4145.9816	475.84092	0
Residual	3225	28099.28717	8.7129573		
Total	3230	48829.19516			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	24.504975	0.200711218	122.09071	0	24.111441	24.89851	24.111441	24.89851
Hour	-0.010189	0.015644815	-0.651261	0.5149245	-0.0408636	0.0204859	-0.040864	0.0204859
Sin(Pi*Hour/12)	-2.581376	0.13913401	-18.55316	4.305E-73	-2.8541762	-2.308576	-2.854176	-2.308576
Cos(Pi*Hour/12)	-2.323163	0.075080586	-30.94226	2.62E-184	-2.4703738	-2.175953	-2.470374	-2.175953
Sin(Pi*Hour/6)	0.7917929	0.094191603	8.4061944	6.27E-17	0.60711147	0.9764744	0.6071115	0.9764744
Cos(Pi*Hour/6)	0.6565048	0.074151376	8.8535749	1.371E-18	0.51111617	0.8018934	0.5111162	0.8018934



Min Regress	21.16
Max Regress	28.71
Difference	7.55
Difference/12	0.6295

Figure 34. September Charleston AFB Temperature Regression Output

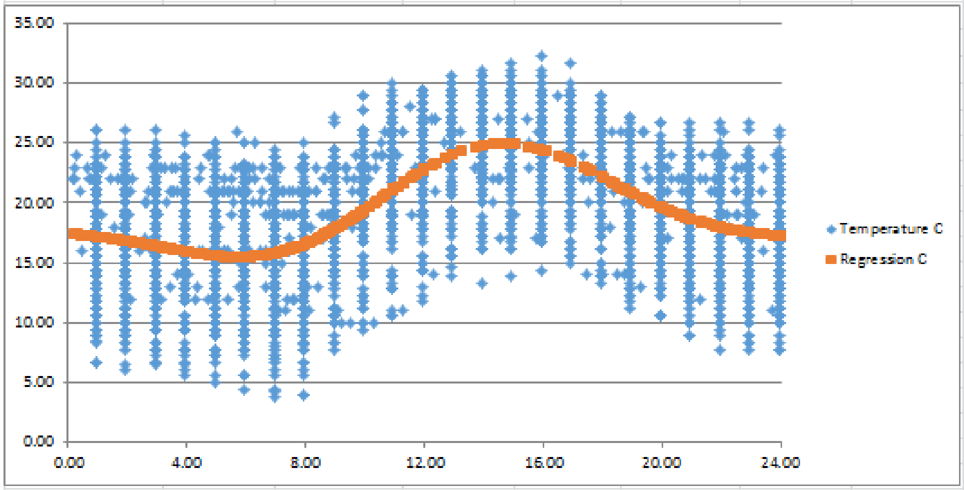
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.5928782
R Square	0.3515045
Adjusted R Square	0.3505025
Standard Error	4.3110039
Observations	3242

ANOVA

	df	SS	MS	F	Significance F
Regression	5	32597.87503	6519.575	350.80232	4.736E-301
Residual	3236	60140.26536	18.584754		
Total	3241	92738.1404			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	19.662164	0.292949004	67.118044	0	19.0877797	20.236548	19.08778	20.236548
Hour	-0.010857	0.02280721	-0.476039	0.6340789	-0.0555752	0.0338609	-0.055575	0.0338609
Sin(Pi*Hour/12)	-3.361412	0.203094612	-16.55097	3.973E-59	-3.7596194	-2.963205	-3.759619	-2.963205
Cos(Pi*Hour/12)	-2.767639	0.109348683	-25.31022	4.13E-129	-2.982039	-2.55324	-2.982039	-2.55324
Sin(Pi*Hour/6)	1.1523415	0.137378306	8.3880892	7.281E-17	0.88298421	1.4216988	0.8829842	1.4216988
Cos(Pi*Hour/6)	0.6433831	0.108533407	5.9279733	3.39E-09	0.43058198	0.8561843	0.430582	0.8561843



Min Regress	15.58
Max Regress	25.03
Difference	9.45
Difference/12	0.7878

Figure 35. October Charleston AFB Temperature Regression Output

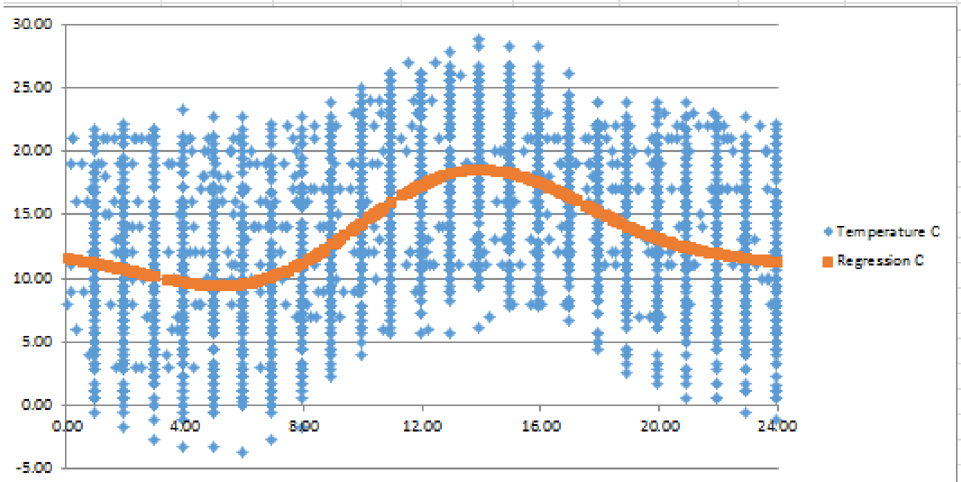
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.4923416
R Square	0.2424002
Adjusted R Square	0.2412264
Standard Error	5.3586507
Observations	3233

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	29648.5188	5929.7038	206.50097	1.749E-191
Residual	3227	92663.74749	28.715137		
Total	3232	122312.2663			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	13.586121	0.36117061	37.616907	4.16E-257	12.8779744	14.294268	12.877974	14.294268
Hour	-0.013416	0.028220148	-0.4754	0.6345338	-0.0687471	0.0419154	-0.068747	0.0419154
Sin(Pi*Hour/12)	-2.858473	0.252026021	-11.34197	2.89E-29	-3.3526198	-2.364325	-3.35262	-2.364325
Cos(Pi*Hour/12)	-3.011108	0.135398703	-22.23883	4.64E-102	-3.2765845	-2.745632	-3.276584	-2.745632
Sin(Pi*Hour/6)	0.7593422	0.170461625	4.4546227	8.689E-06	0.42511822	1.0935662	0.4251182	1.0935662
Cos(Pi*Hour/6)	1.025893	0.134822622	7.6092055	3.596E-14	0.7615464	1.2902397	0.7615464	1.2902397



Min Regress	9.47
Max Regress	18.61
Difference	9.14
Difference/12	0.7617

Figure 36. November Charleston AFB Temperature Regression Output

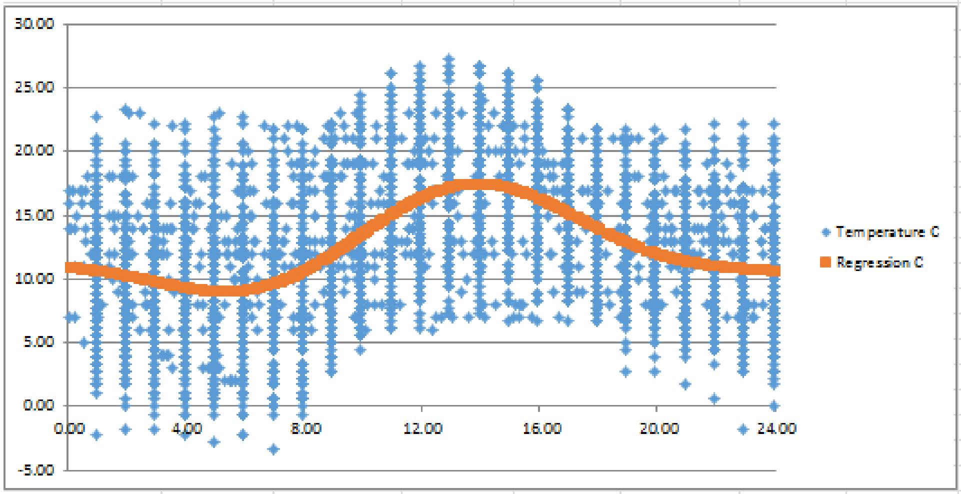
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.4946706
R Square	0.244699
Adjusted R Square	0.2436169
Standard Error	4.8973841
Observations	3496

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	27118.51197	5423.7024	226.13486	1.39E-209
Residual	3490	83705.45359	23.984371		
Total	3495	110823.9656			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	12.793831	0.315241634	40.584206	2.56E-295	12.1757548	13.411908	12.175755	13.411908
Hour	-0.012018	0.024616804	-0.488219	0.6254255	-0.0602832	0.0362464	-0.060283	0.0362464
Sin(Pi*Hour/12)	-2.45918	0.221076863	-11.12364	2.86E-28	-2.8926335	-2.025727	-2.892633	-2.025727
Cos(Pi*Hour/12)	-2.852079	0.118417293	-24.08499	1.06E-118	-3.0842532	-2.619905	-3.084253	-2.619905
Sin(Pi*Hour/6)	0.8235764	0.149093269	5.5239009	3.558E-08	0.53125763	1.1158953	0.5312576	1.1158953
Cos(Pi*Hour/6)	1.0414143	0.118687731	8.7744059	2.639E-18	0.80870995	1.2741187	0.8087099	1.2741187



Min Regress	9.12
Max Regress	17.57
Difference	8.45
Difference/12	0.7042

Figure 37. December Charleston AFB Temperature Regression Output

Appendix C: Four-Hour Charleston AFB Flight Profile

MISSION ID	DATE OF TAKEOF	SQUADRON	AIRCRAFT TYPE
			C-17A

Takeoff Time (Z) : 00:00.0	Fuel Load : 80000	Fuel On Board : 04+19.9
Land Time (Z) :	Fuel Used : 60034	Acft Gross Wt : 365000
Sched Duration : 04+00.7	Remarks:	

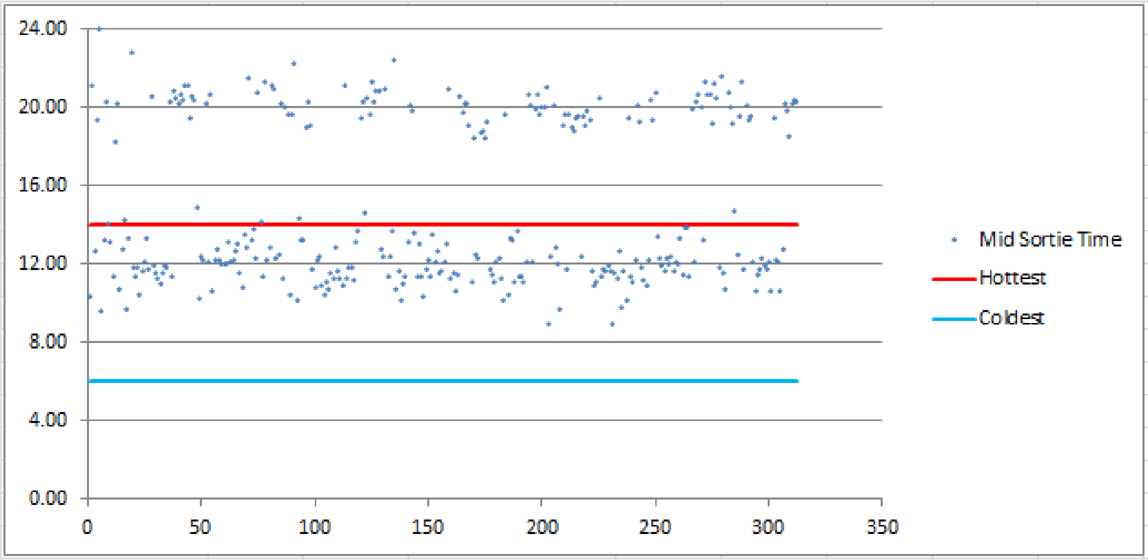
WP#	FIX	TAC	LATITUDE	TC	W/V	TH	TEMP	CAS	TAS	GS	DIST	TIME	ETA	GROSS	LEG FUEL
	REMARKS	VOR	LONGITUDE	MC	DC	MH	ALT	MAC			ACDIST	ACTIME	ATA	WIEGHT	FUEL RMN
1	KCHS/A		N32 5355.13	023		023	+15C				1	+00.0	00:00.0		2500
	CHARLESTON /		W0800225.90	031	0	031	45M				1	+00.0		362500	77500
2	LOIRN/W		N33 0041.22	070		070	-6C	N/A	N/A	N/A	17	+03.6	00:03.6		2221
	LOIRN		W0794323.38	077	0	077	10721M	N/A			18	+03.6		360279	75279
	.level off		N33 0100.90	057		057	-7C	N/A	N/A	N/A	1	+00.1	00:03.7		56
			W0794247.22	065	0	065	11000M	N/A			18	+03.7		360223	75223
3	PLMTO/W		N33 1200.44	057		057	-7C	250	293	293	20	+04.2	00:07.8		928
	PLMTO		W0792229.38	065	0	065	11000M	.46			39	+07.8		359295	74295
	.descent pt		N33 4501.46	042		042	-7C	250	293	293	44	+09.0	00:16.8		2011
			W0784732.49	050	0	050	11000M	.46			83	+16.8		357284	72284
4	CRE/R	123X	N33 4849.86	042		042	-4C	N/A	N/A	N/A	5	+01.0	00:17.9		74
	GRAND STRAN	117.60	W0784328.32	050	0	050	9689M	N/A			88	+17.9		357210	72210
5	IR035 A	123X	N33 5500.00	074		074	+7C	N/A	N/A	N/A	22	+04.5	00:22.4		319
	CRE/R077022	117.60	W0781800.00	083	0	083	4000M	N/A			110	+22.4		356891	71891
6	IR035 B	123X	N34 2700.00	004		004	+14C	310	311	311	32	+06.2	00:28.5		1991
	CRE/R035045	117.60	W0781500.00	014	0	014	319M	.47			142	+28.5		354900	69900
7	IR035 C	099X	N34 2700.00	270		270	+14C	310	311	311	36	+06.9	00:35.4		2204
	FLO/R072037	115.20	W0785800.00	279	0	279	382M	.47			177	+35.4		352696	67696
8	IR035 D	099X	N33 5700.00	210		210	+14C	310	311	311	35	+06.7	00:42.1		2148
	FLO/R138024	115.20	W0791900.00	219	0	219	313M	.47			212	+42.1		350548	65548
9	IR035 E	099X	N33 5800.00	272		272	+14C	310	312	312	37	+07.1	00:49.1		2260
	FLO/R234025	115.20	W0800300.00	280	0	280	421M	.47			249	+49.1		348288	63288
10	IR035 F	041X	N33 3600.00	229		229	+14C	310	312	312	33	+06.4	00:55.5		2051
	VAN/R332009	110.40	W0803300.00	236	0	236	437M	.47			282	+55.5		346237	61237
11	IR035 G	094X	N33 3600.00	270		270	+9C	250	261	261	26	+06.0	01:01.5		1377
	CAE/R184015	114.70	W0810400.00	277	0	277	3000M	.40			308	01+01.5		344860	59860
12	VAN/R	041X	N33 2829.39	104		104	+9C	250	261	261	32	+07.3	01:08.8		1692
	VANCE	110.40	W0802655.11	111	0	111	3000M	.40			340	01+08.8		343168	58168
13	FLO/R	099X	N34 1358.69	041		041	+9C	250	261	261	60	+13.9	01:22.7		3185
	FLORENCE	115.20	W0793925.78	049	0	049	3000M	.40			400	01+22.7		339983	54983
	.level off		N34 3119.68	070		070	-35C	N/A	N/A	N/A	51	+08.3	01:31.0		4460
			W0784124.70	079	0	079	25000M	N/A			451	01+31.0		335523	50523
14	LAYZE/W		N34 4144.62	071		071	-35C	250	363	363	31	+05.2	01:36.1		1068
	LAYZE		W0780537.21	080	0	080	25000M	.60			482	01+36.1		334455	49455
15	.PREARIP	117X	N34 3607.49	117		117	-35C	285	411	411	12	+01.8	01:37.9		437
	ILM/R007015	117.00	W0775227.76	127	0	127	25000M	.68			495	01+37.9		334018	49018
16	.AR202SIP	117X	N34 2105.96	180		180	-35C	285	411	411	15	+02.2	01:40.1		536
	ILM/R	117.00	W0775227.76	189	0	189	25000M	.68			510	01+40.1		333482	48482
17	.AR202SCP	117X	N32 4054.80	180		180	-37C	265	390	390	100	+15.4	01:55.5		3383
	ILM/R187100	117.00	W0775227.76	189	0	189	26000M	.65			610	01+55.5		330099	45099
18	OLDEY/W		N32 1544.21	178		178	-37C	265	390	390	25	+03.9	01:59.4		849
	OLDEY		W0775113.81	187	0	187	26000M	.65			635	01+59.4		329250	44250

Figure 38. Four-Hour Charleston AFB Flight Profile

19	.AR202SC	117X	N30 1836.21	181		181	-37C	265	390	390	117	+18.0	02:17.4		3932
	ILM/R187242	117.00	W0775227.7	189	0	189	26000N	.65			752	02+17.4		325318	40318
20	.AR202NIP	120X	N28 1115.55	180		180	-37C	265	390	390	127	+19.6	02:36.9		4251
	TRV/R084142	117.30	W0775247.6	189	0	189	26000N	.65			879	02+36.9		321067	36067
21	.AR202NCP	117X	N30 1836.21	360		360	-37C	265	390	390	127	+19.6	02:56.5		4229
	ILM/R187242	117.00	W0775227.7	009	0	009	26000N	.65			1006	02+56.5		316838	31838
22	OLDEY/W		N32 1544.21	001		001	-37C	265	390	390	117	+18.0	03:14.5		3873
	OLDEY		W0775113.81	009	0	009	26000N	.65			1122	03+14.5		312965	27965
23	.AR202NC	117X	N32 4054.80	358		358	-37C	265	390	390	25	+03.9	03:18.4		831
	ILM/R187100	117.00	W0775227.7	007	0	007	26000N	.65			1148	03+18.4		312134	27134
24	.AR202NEX	117X	N34 2105.96	360		360	-35C	250	363	363	100	+16.5	03:34.9		3289
	ILM/R	117.00	W0775227.7	009	0	009	25000N	.60			1248	03+34.9		308845	23845
25	BARTL/W		N34 1811.44	266		266	-35C	250	363	363	39	+06.4	03:41.3		1269
	BARTL		W0783905.3	275	0	275	25000N	.60			1286	03+41.3		307576	22576
	.descent pt		N34 1223.04	223		223	-35C	250	363	363	8	+01.3	03:42.6		262
			W0784544.4	232	0	232	25000N	.60			1294	03+42.6		307314	22314
26	AMYLU/W		N33 4715.50	223		223	-5C	N/A	N/A	N/A	35	+05.6	03:48.2		287
	AMYLU		W0791416.16	232	0	232	10000M	N/A			1329	03+48.2		307027	22027
	.descent pt		N33 2259.89	217		217	-5C	250	289	289	30	+06.3	03:54.5		1310
			W0793559.8	225	0	225	10000M	.45			1359	03+54.5		305717	20717
27	.APPROACH		N33 1023.14	217		217	+5C	N/A	N/A	N/A	16	+03.3	03:57.7		251
			W0794711.46	225	0	225	5000M	N/A			1375	03+57.7		305466	20466
28	KCHS/A		N32 5355.13	218		218	+15C				21	+03.0	04:00.7		500
	CHARLESTON /		W0800225.9	226	0	226	45M				1396	04+00.7		304966	19966

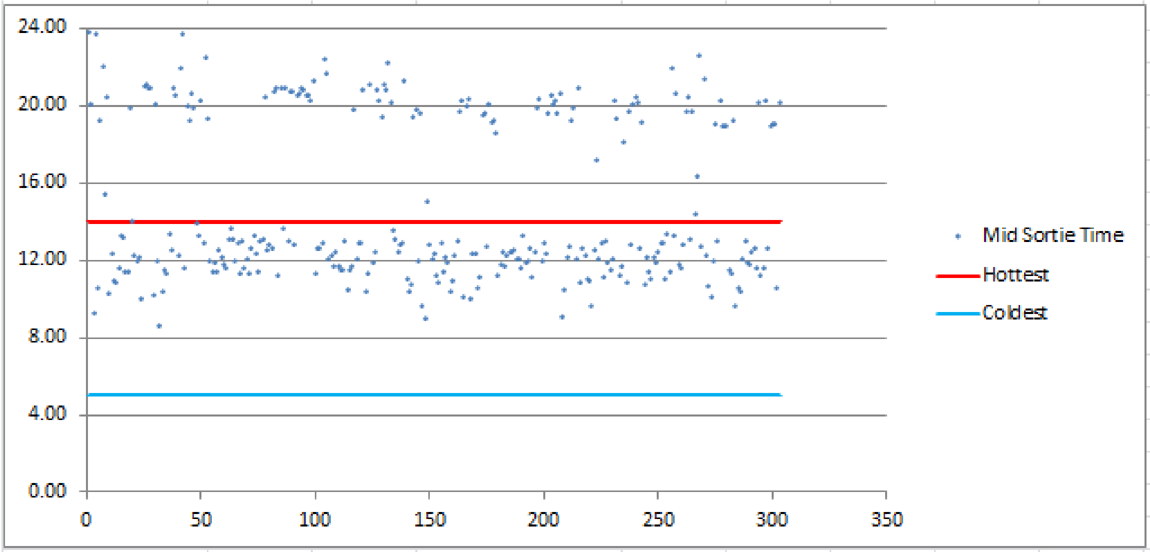
Figure 38. Four-Hour Charleston AFB Flight Profile (continued)

Appendix D: Charleston AFB Midpoint Flight Time Output



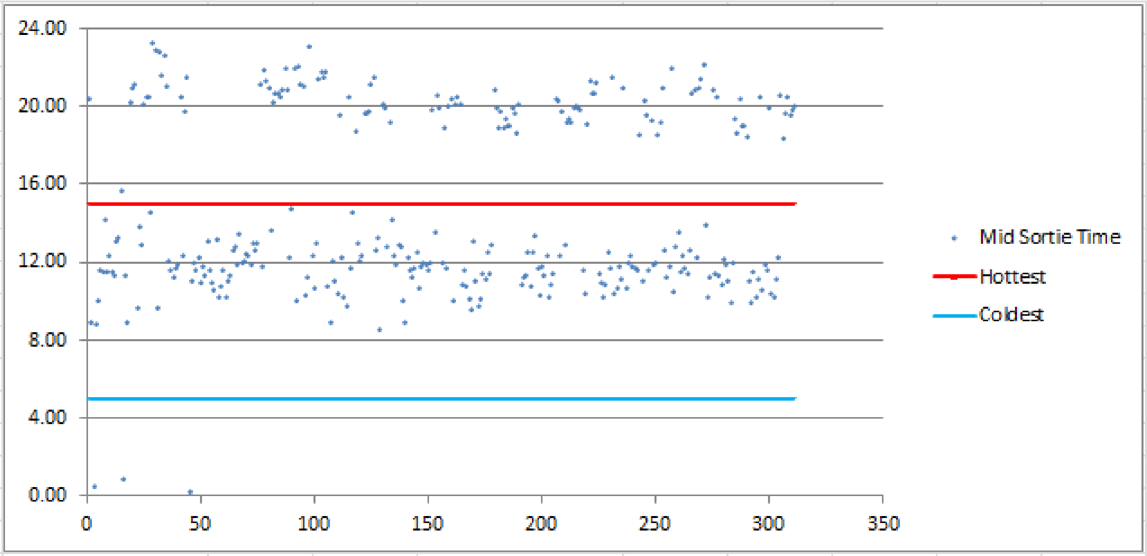
Mid Sortie Time			0700-1600 Mid Sortie Time	
Mean	14.87		Mean	11.91
Standard Error	0.23		Standard Error	0.07
Median	12.65		Median	11.85
Mode	12.23		Mode	12.23
Standard Deviation	4.09		Standard Deviation	1.06
Sample Variance	16.73		Sample Variance	1.11
Kurtosis	-1.48		Kurtosis	0.39
Skewness	0.52		Skewness	0.17
Range	15.08		Range	5.96
Minimum	8.91		Minimum	8.91
Maximum	23.98		Maximum	14.87
Sum	4639.60		Sum	2381.58
Count	312.00		Count	200.00

Figure 39. January Charleston AFB Midpoint Flight Time Output



Mid Sortie Time			*0700-1600 Mid Sortie Time*	
Mean	14.81		Mean	11.94
Standard Error	0.24		Standard Error	0.08
Median	12.73		Median	12.03
Mode	12.88		Mode	12.88
Standard Deviation	4.12		Standard Deviation	1.06
Sample Variance	17.00		Sample Variance	1.12
Kurtosis	-1.31		Kurtosis	0.83
Skewness	0.61		Skewness	-0.26
Range	15.20		Range	6.86
Minimum	8.58		Minimum	8.58
Maximum	23.78		Maximum	15.44
Sum	4487.25		Sum	2376.13
Count	303.00		Count	199.00

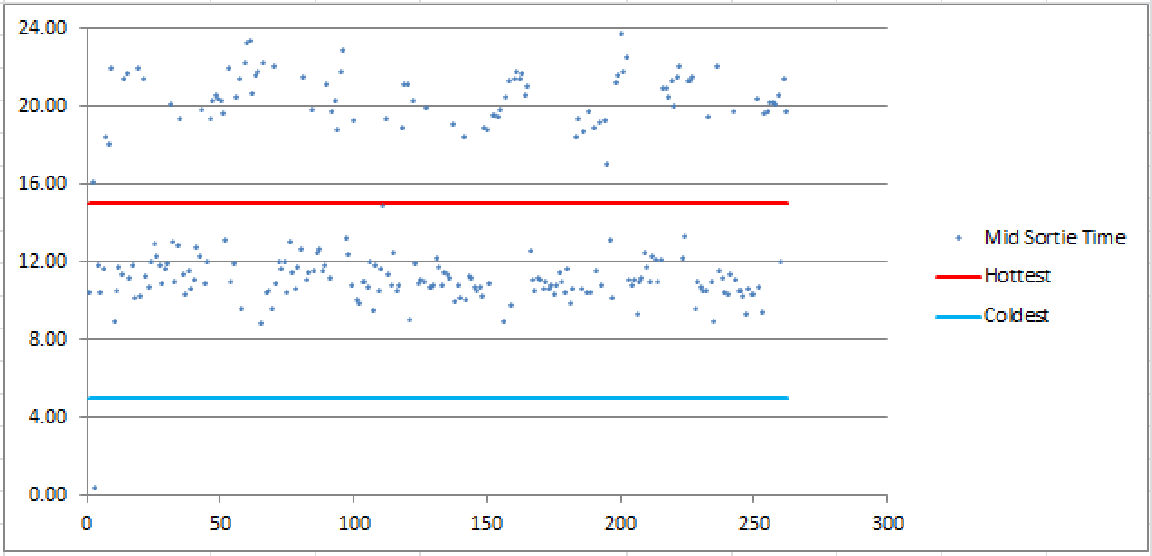
Figure 40. February Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.74
Standard Error	0.26
Median	12.48
Mode	20.10
Standard Deviation	4.59
Sample Variance	21.06
Kurtosis	-0.82
Skewness	0.19
Range	22.95
Minimum	0.26
Maximum	23.21
Sum	4583.94
Count	311.00

0700-1600 Mid Sortie Time	
Mean	11.61
Standard Error	0.09
Median	11.61
Mode	11.58
Standard Deviation	1.18
Sample Variance	1.40
Kurtosis	0.64
Skewness	0.16
Range	7.15
Minimum	8.54
Maximum	15.69
Sum	2240.50
Count	193.00

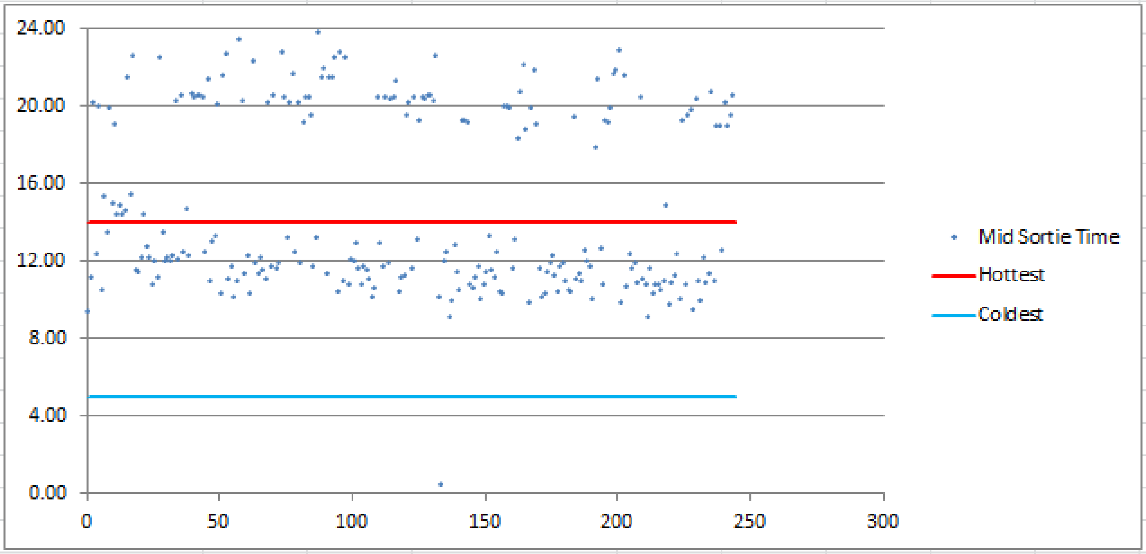
Figure 41. March Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.43
Standard Error	0.29
Median	11.80
Mode	10.95
Standard Deviation	4.72
Sample Variance	22.28
Kurtosis	-1.20
Skewness	0.50
Range	23.32
Minimum	0.39
Maximum	23.71
Sum	3779.88
Count	262.00

0700-1600 Mid Sortie Time	
Mean	11.10
Standard Error	0.07
Median	10.99
Mode	10.95
Standard Deviation	0.96
Sample Variance	0.93
Kurtosis	0.99
Skewness	0.39
Range	6.02
Minimum	8.83
Maximum	14.85
Sum	1854.04
Count	167.00

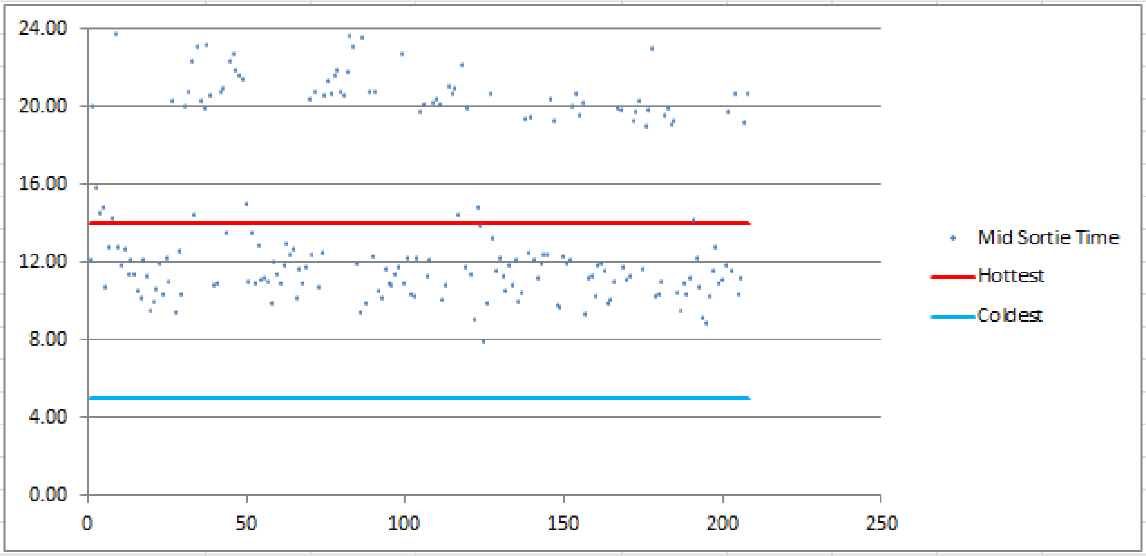
Figure 42. April Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.89
Standard Error	0.29
Median	12.36
Mode	11.67
Standard Deviation	4.59
Sample Variance	21.06
Kurtosis	-1.18
Skewness	0.37
Range	23.30
Minimum	0.53
Maximum	23.83
Sum	3632.63
Count	244.00

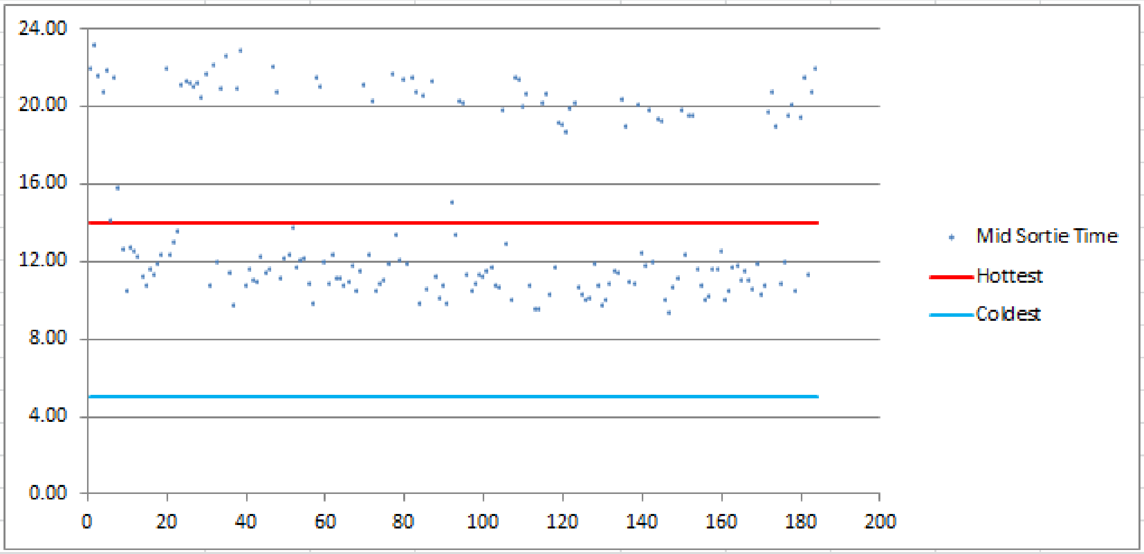
0700-1600 Mid Sortie Time	
Mean	11.63
Standard Error	0.10
Median	11.54
Mode	11.67
Standard Deviation	1.25
Sample Variance	1.55
Kurtosis	0.96
Skewness	0.86
Range	6.33
Minimum	9.10
Maximum	15.43
Sum	1779.49
Count	153.00

Figure 43. May Charleston AFB Midpoint Flight Time Output



Mid Sortie Time			0700-1600 Mid Sortie Time	
Mean	14.53		Mean	11.43
Standard Error	0.32		Standard Error	0.11
Median	12.13		Median	11.28
Mode	10.86		Mode	10.86
Standard Deviation	4.59		Standard Deviation	1.34
Sample Variance	21.11		Sample Variance	1.79
Kurtosis	-1.29		Kurtosis	0.86
Skewness	0.63		Skewness	0.62
Range	15.78		Range	7.83
Minimum	7.96		Minimum	7.96
Maximum	23.73		Maximum	15.78
Sum	3021.31		Sum	1588.43
Count	208.00		Count	139.00

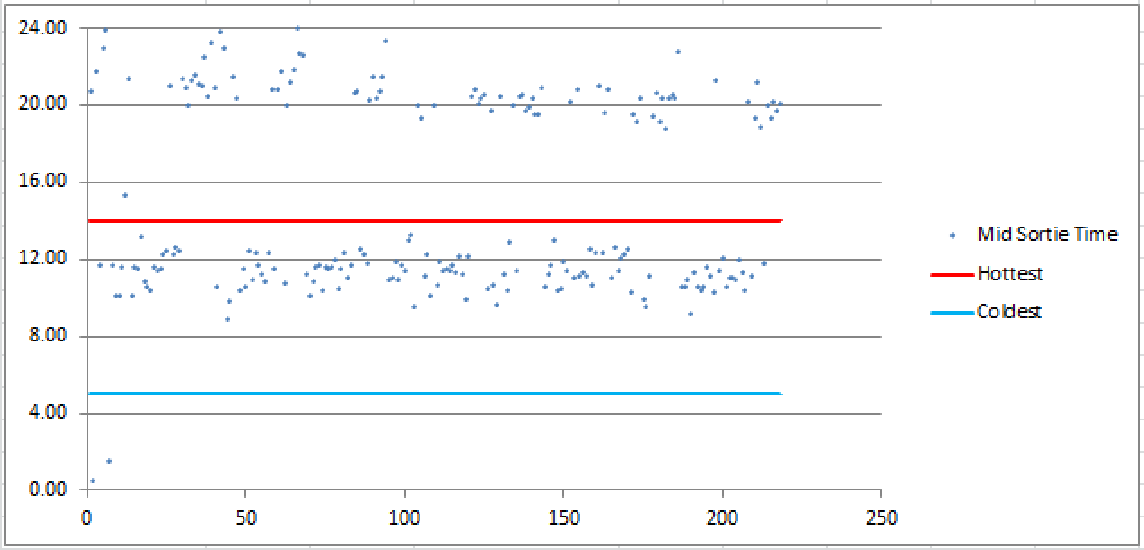
Figure 44. June Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.55
Standard Error	0.34
Median	11.95
Mode	10.49
Standard Deviation	4.58
Sample Variance	20.94
Kurtosis	-1.44
Skewness	0.62
Range	13.72
Minimum	9.38
Maximum	23.10
Sum	2676.50
Count	184.00

0700-1600 Mid Sortie Time	
Mean	11.34
Standard Error	0.10
Median	11.21
Mode	10.49
Standard Deviation	1.08
Sample Variance	1.18
Kurtosis	2.43
Skewness	1.08
Range	6.44
Minimum	9.38
Maximum	15.83
Sum	1372.43
Count	121.00

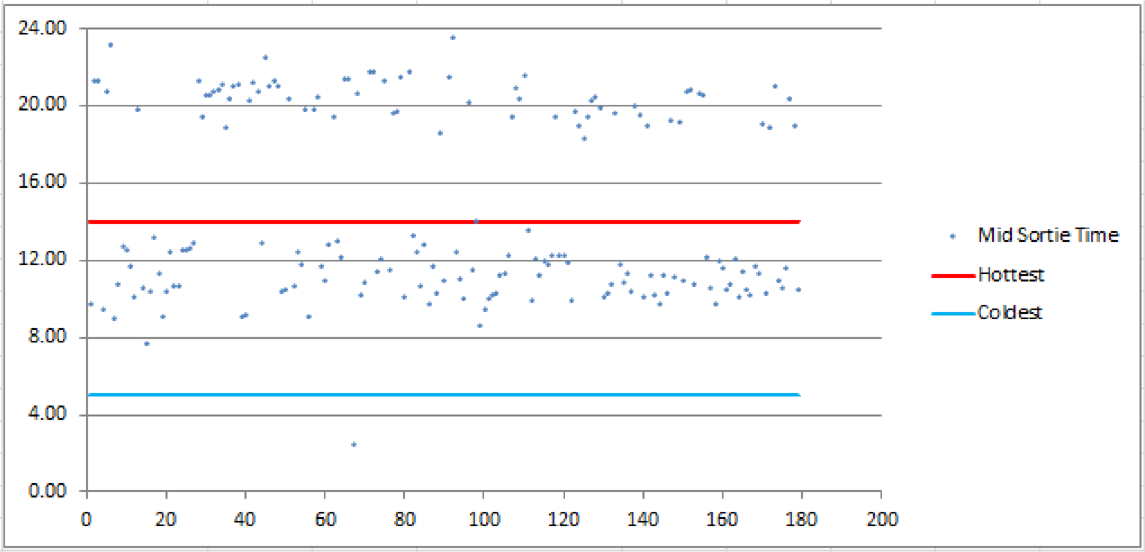
Figure 45. July Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.87
Standard Error	0.33
Median	12.17
Mode	11.67
Standard Deviation	4.90
Sample Variance	24.03
Kurtosis	-1.13
Skewness	0.28
Range	23.43
Minimum	0.55
Maximum	23.98
Sum	3240.99
Count	218.00

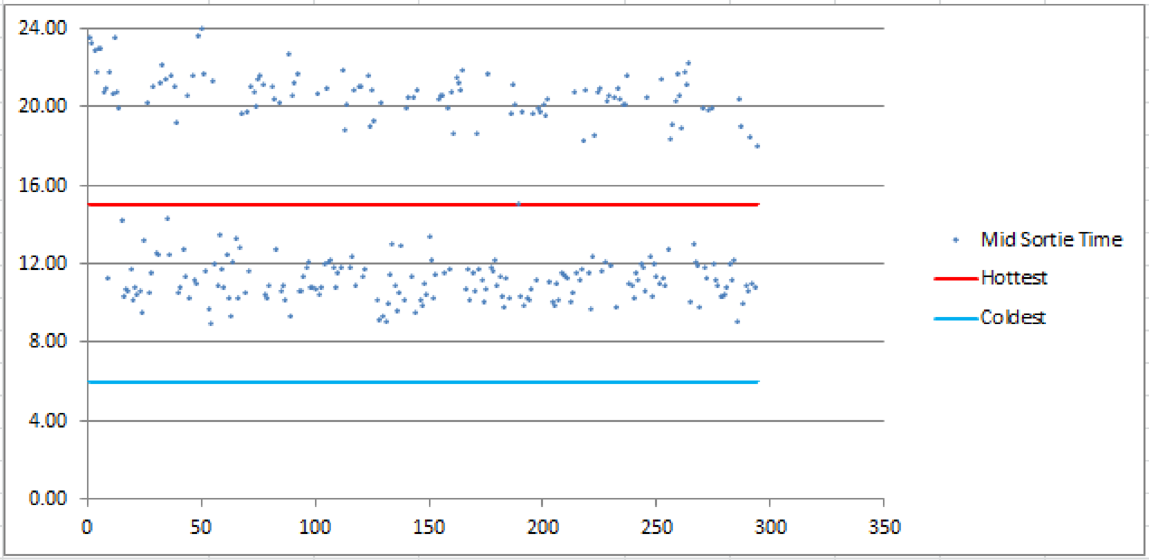
0700-1600 Mid Sortie Time	
Mean	11.31
Standard Error	0.08
Median	11.32
Mode	11.67
Standard Deviation	0.92
Sample Variance	0.85
Kurtosis	2.04
Skewness	0.49
Range	6.48
Minimum	8.87
Maximum	15.35
Sum	1493.27
Count	132.00

Figure 46. August Charleston AFB Midpoint Flight Time Output



Mid Sortie Time		*0700-1600 Mid Sortie Time*	
Mean	14.65	Mean	11.09
Standard Error	0.36	Standard Error	0.11
Median	12.27	Median	10.98
Mode	19.42	Mode	10.13
Standard Deviation	4.78	Standard Deviation	1.17
Sample Variance	22.83	Sample Variance	1.37
Kurtosis	-1.44	Kurtosis	-0.16
Skewness	0.34	Skewness	-0.01
Range	21.04	Range	6.37
Minimum	2.47	Minimum	7.68
Maximum	23.51	Maximum	14.04
Sum	2621.50	Sum	1208.78
Count	179.00	Count	109.00

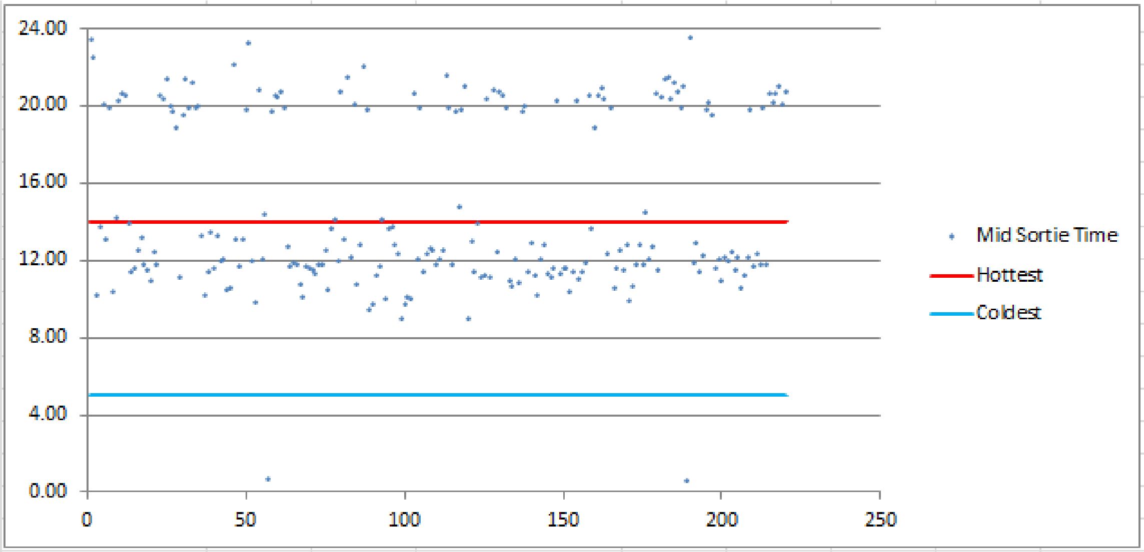
Figure 47. September Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.81
Standard Error	0.28
Median	11.98
Mode	11.38
Standard Deviation	4.79
Sample Variance	22.98
Kurtosis	-1.59
Skewness	0.47
Range	15.02
Minimum	8.93
Maximum	23.95
Sum	4354.61
Count	294.00

0700-1600 Mid Sortie Time	
Mean	11.13
Standard Error	0.08
Median	10.94
Mode	11.38
Standard Deviation	1.04
Sample Variance	1.07
Kurtosis	0.96
Skewness	0.63
Range	6.13
Minimum	8.93
Maximum	15.07
Sum	2014.38
Count	181.00

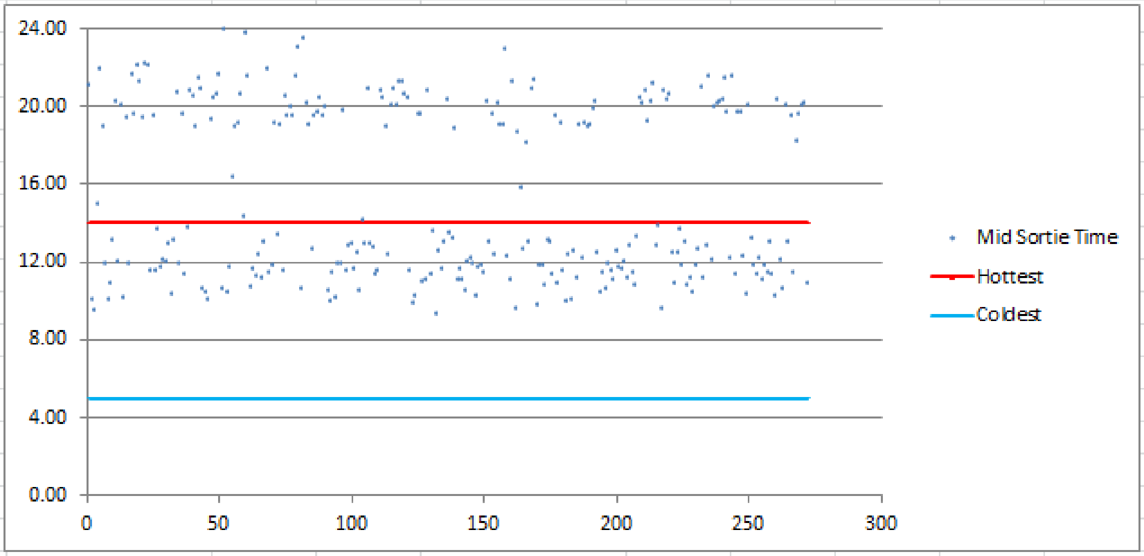
Figure 48. October Charleston AFB Midpoint Flight Time Output



Mid Sortie Time	
Mean	14.74
Standard Error	0.30
Median	12.53
Mode	11.78
Standard Deviation	4.47
Sample Variance	20.02
Kurtosis	-0.73
Skewness	0.27
Range	22.87
Minimum	0.61
Maximum	23.48
Sum	3242.48
Count	220.00

0700-1600 Mid Sortie Time	
Mean	11.84
Standard Error	0.10
Median	11.78
Mode	11.78
Standard Deviation	1.14
Sample Variance	1.30
Kurtosis	0.12
Skewness	0.12
Range	5.84
Minimum	8.96
Maximum	14.80
Sum	1680.78
Count	142.00

Figure 49. November Charleston AFB Midpoint Flight Time Output

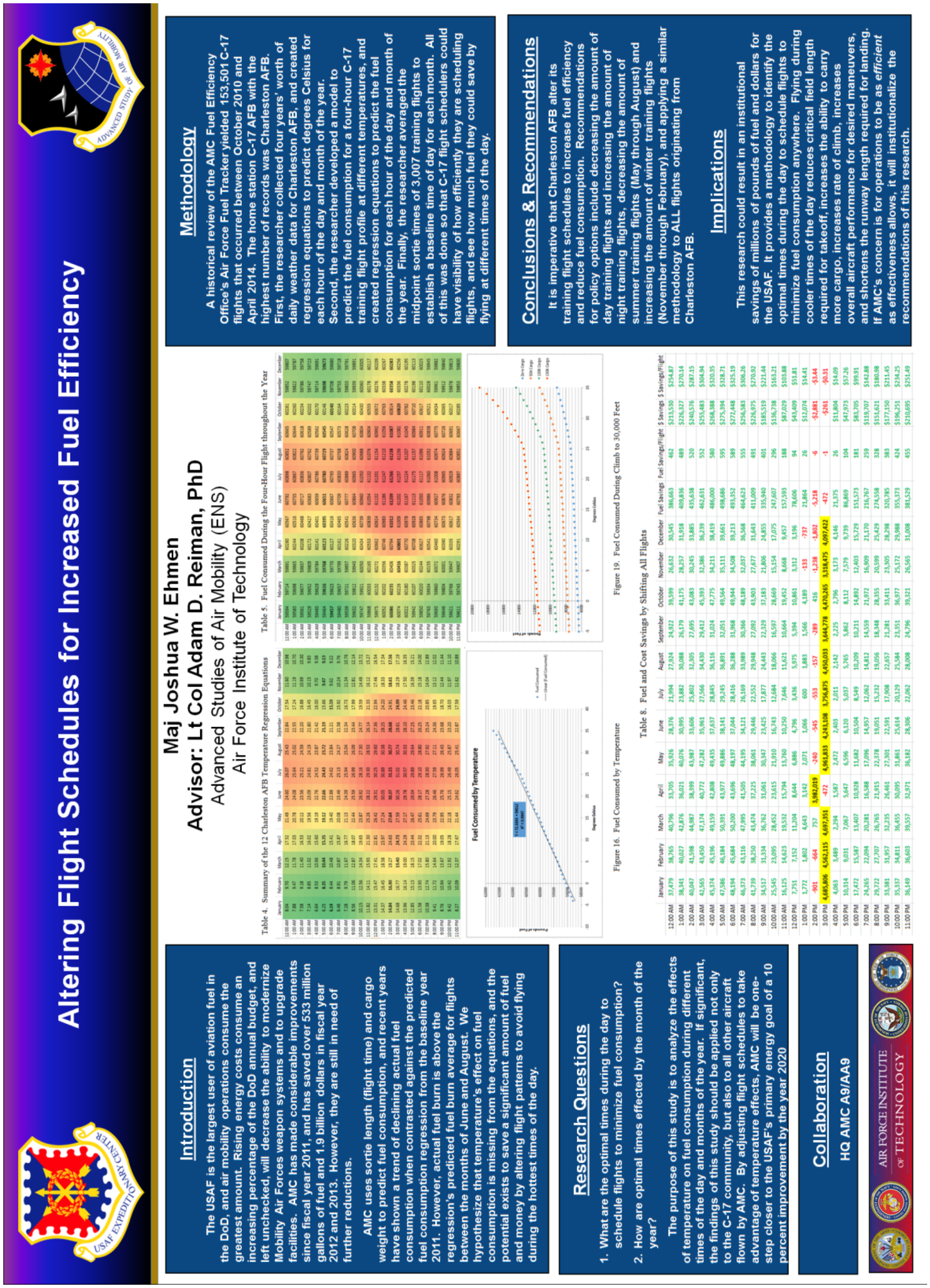


Mid Sortie Time	
Mean	15.34
Standard Error	0.26
Median	13.03
Mode	19.01
Standard Deviation	4.36
Sample Variance	19.05
Kurtosis	-1.63
Skewness	0.32
Range	14.62
Minimum	9.34
Maximum	23.96
Sum	4172.88
Count	272.00

0700-1600 Mid Sortie Time	
Mean	11.80
Standard Error	0.09
Median	11.73
Mode	11.92
Standard Deviation	1.13
Sample Variance	1.28
Kurtosis	0.38
Skewness	0.38
Range	6.49
Minimum	9.34
Maximum	15.83
Sum	1875.88
Count	159.00

Figure 50. December Charleston AFB Midpoint Flight Time Output

Appendix E: Quad Chart



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14. ABSTRACT Air Mobility Command (AMC) has made considerable improvements to reduce fuel consumption over the years, but failed to account for temperature effects in their efficiency equations. The purpose of this research was to analyze the effects of temperature on fuel consumption during different times of the day and months of the year. To accomplish this, the researcher created a temperature model for Charleston Air Force Base (AFB) for all months of the year, and modeled the fuel consumption for a four-hour training flight profile for each hour of the day. After analysis, it is imperative that Charleston AFB alter its training flight schedules to increase fuel efficiency and reduce fuel consumption. Recommendations for policy options include decreasing the amount of day training flights and increasing the amount of night training flights, decreasing the amount of summer training flights (May through August) and increasing the amount of winter training flights (November through February), and applying a similar methodology to ALL flights originating from Charleston AFB. Though C-17 flights at Charleston AFB were the focus of this study, the findings should benefit all C-17 operating locations and other aircraft operated by AMC and the United States Air Force.			
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